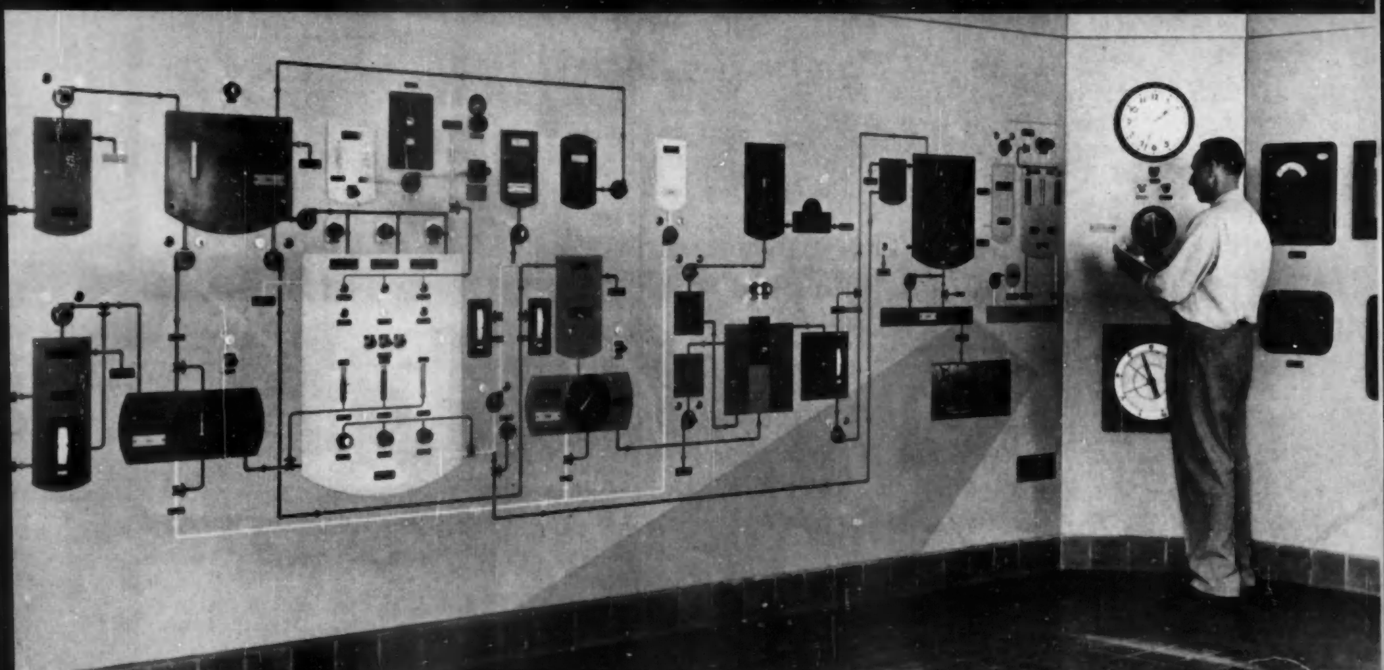
Control ENGINEERING

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

A NEW McGRAW-HILL PUBLICATION

Price 50 Cents

OCTOBER 1954



IN THIS ISSUE:


Librascope's
COMBINED TECHNIQUES
gives you faster, more efficient solutions to computer-control problems
What is the best possible solution to your individual computing-controlling problem? Do you require a handful or a roomful of equipment? Should the system be mechanical, electrical, electronic, magnetic or a combination?
Librascope has a broad background in all of these fields. By combining techniques applied successfully for nearly two decades in computing-controlling manufacture, Librascope is equipped to make an impartial evaluation of your problem and suggest the proper solution—one that will save you time and money and meet your most exacting requirements. Consult Librascope today.
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ELECTRONIC
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ELECTRICAL
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MAGNETIC
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FOR EXAMPLE:
Librascope's Sine Wave Generator was designed for a major oil company. It is used to determine transfer functions of components in automatic control systems, and to define the physical properties of existing plants to which control systems are to be added. We solved this problem in minimum time and at moderate cost. If your industry requires equipment for computing or controlling designed around your individual problem, investigate Librascope's techniques.
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A careful review of operations within your plant may disclose the fact that a variety of functions are inefficiently handled manually . . . turning "off" and "on" valves, switches, or operating other controls at remote points. Perhaps the persons performing these functions do so only after receiving telephoned orders from a central dispatch point, and otherwise have little else to do.

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Fill out and send the coupon below, or write immediately for detailed information on how you can cut your operating costs by using Hammarlund Remote Control and Signaling Equipment. If you send a brief description of your requirements, Hammarlund engineers will analyze them and suggest the most efficient system. No obligation, of course.

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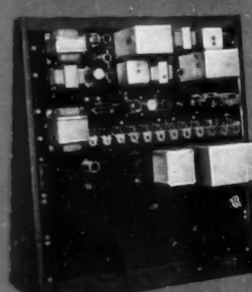
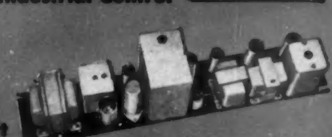
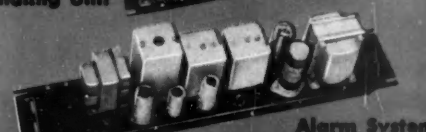


Aircraft Communications Control

Multi-Gate® Industrial Control



Duplex Signaling Unit



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Control ENGINEERING

OCTOBER 1954

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

FEATURE ARTICLES

IDEAS AT WORK

DEPARTMENTS

ADVERTISING INDEX page 102

PRINT ORDER THIS ISSUE 18,861

SHOPTALK FROM EDITOR TO READER

CARE & FEEDING OF CONTROL ELEMENTS

Twice a week, operators at Oneida, Ltd., shove a few specks of fresh shrimp into the graphic panel shown on the cover. Ridiculous? Far from it. The control elements love shrimp. You see, the panel ties in with the upstate New York silver company's purification of waste water discharged into Sconondoa Creek. Tropical fish—barbs, guppies, and pearl danises—swim in the aquarium that Foxboro engineers set in one corner of the panel. If they thrive, and they do, the water is certainly clean enough for tougher wild fish in the creek. This is more than a clever trick. It exemplifies quality control, goal or many control engineering applications.

LEANER MARKETS THAN YOU THINK

You may not agree with George Attura's article. He thinks a large segment of control manufacturing, now tied to the Armed Forces, is going to have a hard time breaking away from its cost-plus-fixed-fee habits. And he offers tips to companies that want to enter commercial competition.

DEADLINE ANGUISH

Just to make sure it's completely accurate, we like to check each edited article with the author. So, routinely, we mailed the article on eddy-current testing to the West Coast. No answer, and the editorial deadline was snapping at our heels. Checking by telephone, associate editor Byron Ledgerwood learned that Dick Hochschild was vacationing in Baltimore. On a rainy Saturday morning, By hopped a southbound plane. He met Hochschild and rented a room at the Lord Baltimore. There they spent the rest of the day polishing the article and cooking up the table at the end of it.

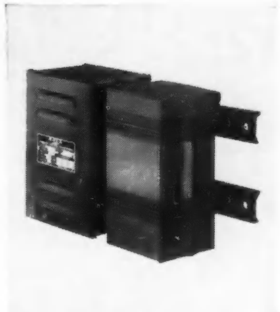
MAN AS A SERVO

Joel Greene's master's thesis attracted plenty of comment. Since we know many control engineers who still have to fit a man into the loop, we hastened to publish this account of how Joel analyzed human dynamics applying to a particular control problem—aiming a gun at an airplane.

DAVE BOYD'S BASEMENT

A lot of people recognize Dave Boyd's professional achievements. Here's the lowdown on life in his basement. You'd be amazed at what goes on there.

STANDARD TYPE CV
Twenty-nine units from 15va to 10kva in a common power line and filament voltage ratings . . . regulation ±1% or less with a total primary variation of 30% . . . for electronic and electrical equipment requiring close regulation.



HARMONIC-NEUTRALIZED TYPE CVH
Six units from 60va to 2kva . . . input range 95-125v, output 115v . . . all the features of the Standard Type CV plus a harmonic neutralizer circuit . . . ±1% regulated voltage with less than 3% harmonic distortion.

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Two ac voltage supply units, 250va and 500va . . . input range 95-125v, output range adjustable from 0-130v . . . regulated ±1%, harmonic distortion less than 3% . . . for general lab work, testing and other applications.

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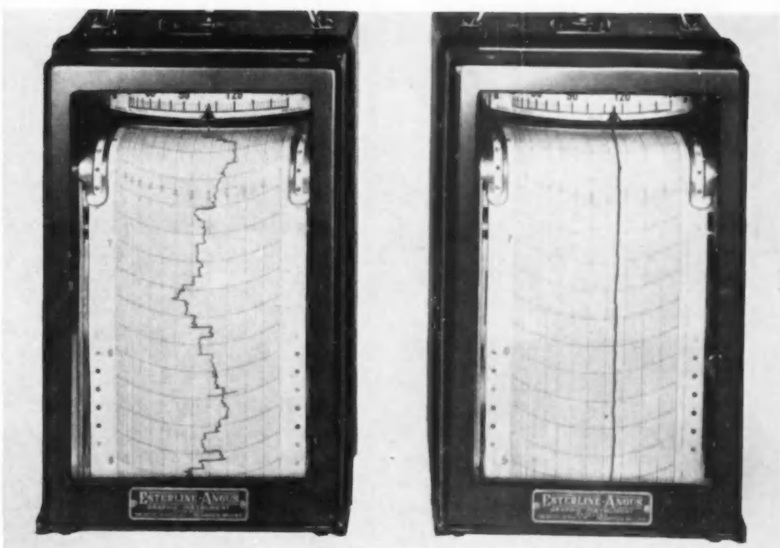
Three units in popular power supply ratings . . . a single, compact source of filament and plate supply voltages . . . regulated to within ±3% or less with line voltage variations of 100-130 volts . . . supplied with separate capacitor for chassis mounting.

±1% stable voltage for automatic control equipment regardless of line voltage variations up to 30%

The voltage-critical elements of electronic and electrical equipment for automatic control cannot operate to performance specifications in face of input voltage fluctuations. Stable input voltage can be easily provided with a Sola Constant Voltage Transformer . . . built in as a component, or used externally as an accessory.

Among the chief advantages of Sola regulators are: continuous, automatic regulation . . . response time 1.5 cycles or less . . . no moving or expendable parts . . . immediate availability of 40 stock units . . . and custom units to your specifications in production quantities.



TYPICAL EXAMPLE OF SOLA VOLTAGE REGULATING ACTION. The recording on the left represents a fairly common condition of voltage fluctuation on a 115v line. The chart on the right was made at exactly the same time from the same line. The primary of the Sola regulator was fed the voltage charted on the left, the voltage charted on the right represents its secondary output, regulated to within ±1% of 115v.

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FEEDBACK FROM READER TO EDITOR

About Vol. I, No. 1

To the Editor—

It has been my privilege to read Vol. I, No. 1 of Control Engineering. It is a most commendable beginning for such a promising undertaking in the control field. In fact, I am a bit disgruntled that I can find so little to criticize. I would strongly urge that you keep a framed copy of the editorial The Common Denominator (page 41) before your editors at all times. Control Engineering is blessed, or cursed, with many ramifications, and the practical, down-to-earth viewpoint should never be overlooked or by-passed.

The section What's New is interesting and in its proper place in the magazine. New Products is good but leans toward the technical or scientific. The abstracts tend to be a bit lengthy, which may have been unavoidable. What's Ahead is important and should list all meetings as far in advance as conveniently possible. And by all means, continue to inject a bit of humor where possible, as you have done so discreetly in No. 1.

J. W. Percy
Research Laboratory
United States Steel Corp.

To the Editor—

We are delighted with the appearance of Vol. I, No. 1. If you can maintain the pace, you will be right up there with Bannister and Landy.

W. W. Lockwood
Advertising Mgr.
Taylor Instrument Cos.

To the Editor—

To you and your associates, congratulations on an excellent first issue of Control Engineering . . . I went through the editorial pages, but I am afraid I have to admit that most of this is not clear to me . . . You see, I am just a worn-out electrical engineer.

Edgar Kobak
New York City

PROBLEM EXCHANGE

Don't forget the problem exchange, which starts in our next issue. Send in control problems, and we'll publish them. Then a couple of months later, we'll print solutions suggested by other readers, plus perhaps some of our own. Modest cash awards will go to whoever submits the most stimulating problems and the most reasonable and imaginative solutions.

As a starter, why not take a crack at the problem suggested by the editor's note at the end of the weigh-belt-feeder article in the Ideas at Work section?

Mr. Kobak was formerly president of the Mutual Broadcasting System.—Ed.

To the Editor—

The initial issue of Control Engineering has reached my office. It represents the first great editorial step forward in bringing under one cover the many aspects of instrumentation. Your new publication will do much to advance the field [of automatic control] and provides an excellent medium for mutual interchange of technological information so essential in this fast-moving industrial-scientific era.

Albert Wiebe
Albert Wiebe & Associates
New York City

To the Editor—

We have read the first issue of Control Engineering with considerable interest, especially in comparison to other publications in this field. There is a rather distinct difference between your magazine and the others, particularly in the high percentage of technical content and analytical treat-

OCTOBER 1954 **Control Engineering** VOL. 1, NO. 2

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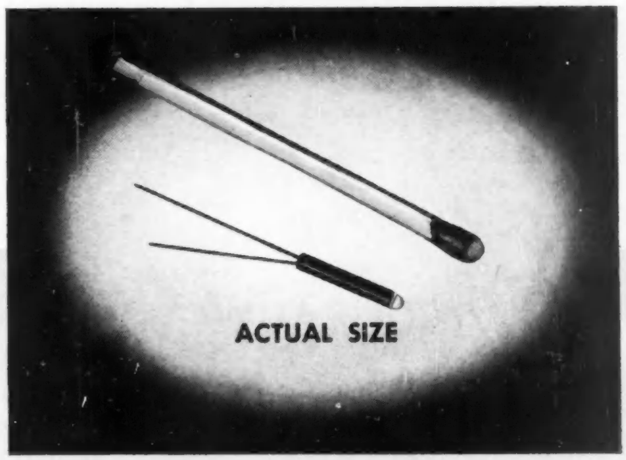

The Sylvania 1N77A is a highly sensitive compact junction photodiode.

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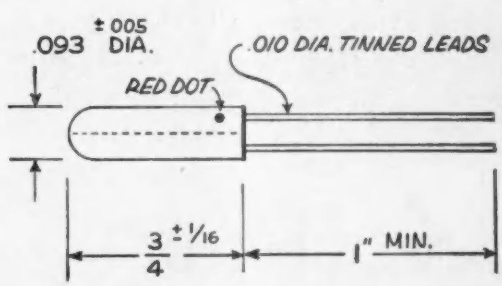
The high sensitivity and compact packaging of the 1N77A should provide the answer to many light-sensing application problems. *Still more reasons why it pays to specify Sylvania.*

DETAILED DRAWING



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ment of control problems.

Your emphasis on techniques and analytical methods makes your magazine of particular interest to us. At the moment we do not know of any other concentrated collection of this sort of material. The articles are very competently presented. We are favorably impressed by the whole format.

With the increasing importance of systems engineering, we are sure there is a very definite need for the publication you have launched.

David N. Smith
Mgr. of Research
Jones & Lamson Machine Co.

Words About Words

To the Editor—

Congratulations on your first issue. Your editorial "Industry's Pulse" appropriately recognizes the need for a common language in the diversified fields in which automatic control applies.

The American Society of Mechanical Engineers has made this a continuing work for an even longer period than indicated in your editorial. Presently, the society hopes, through the American Standards Association and with the cooperation of the groups to which you refer in your editorial, to build into agreement the terminology common in various fields. This will be an arduous task which demands the continued interest and active participation of all those interested in this work. The support, encouragement, and occasional reference to their progress by publications such as yours will assist in keeping the subject alive.

Marc A. Princi, Mgr.
Measurements Lab.
General Electric Co.

Mr. Princi is chairman of the ASME IRD terminology committee.—Ed.

File Cards

To the Editor—

I would like to suggest the introduction of stiff-paper, library-sized file cards on your major articles, as you now do in your Bulletin and Catalogue mailing section. The card should contain a short outline of the contents of the particular article. Since maintaining a card file consumes time, this service would be welcomed by everyone including the librarian.

Alfred O. Kuhnel
Staff Engineer
Mass. Institute of Technology

WHAT'S AHEAD: MEETINGS

OCTOBER

National Electronics Conference, Inc., Hotel Sherman, Chicago, Ill. Oct. 4-9

Society of Automotive Engineers (National Aeronautic Meeting) Statler Hotel. Oct. 4-9

American Institute of Electrical Engineers (fall general meeting) Morrison Hotel, Chicago, Ill. Oct. 11-15

National Conference on Industrial Hydraulics, 10th annual meeting (devoted to hydraulic control), Sheraton Hotel, Chicago, Ill. Oct. 14-15

NOVEMBER

National Electrical Manufacturers Association, Annual Meeting, Haddon Hall Hotel, Atlantic City, New Jersey. Nov. 8-11

American Petroleum Institute, 34th Annual Meeting, Conrad Hilton Hotel and Palmer House, Chicago, Ill. Nov.8-11

American Standards Association (Fifth National Conference on Standards and Thirty-sixth Annual Meeting), Hotel Roosevelt, New York, N. Y. Nov. 15-17

The American Society of Mechanical Engineers, Annual Meeting, Statler Hotel, New York, N. Y. Nov. 28-Dec. 3

DECEMBER

National Exposition of Power and Mechanical Engineering, Commercial Museum, Philadelphia, Pennsylvania. Dec. 2-7

Eastern Computer Conference, Bellevue-Stratford Hotel, Philadelphia, Pa. Dec. 8-10

American Institute of Chemical Engineers, Annual Meeting, Statler Hotel, New York, N. Y. Dec. 12-15

JANUARY

Society of Automotive Engineers, Inc. (Golden Anniversary Annual Meeting), The Sheraton-Cadillac Hotel and Hotel Statler, Detroit, Michigan. Jan. 10-14

American Institute of Electrical Engineers and Institute of Radio Engineers (devoted to high frequency measurements), Hotel Statler, Washington, D. C. Jan. 17-19

American Institute of Electrical Engineers (winter general meeting), Hotel Statler, New York, N. Y. Jan. 31-4

... new

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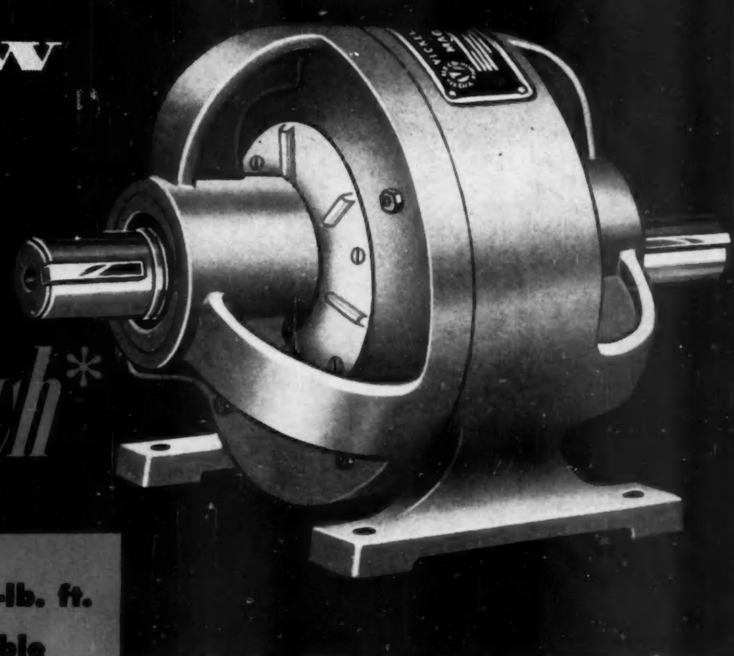

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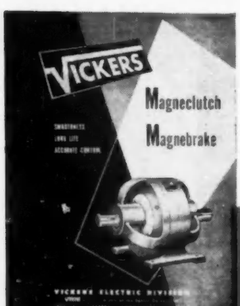

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DAVE BOYD **does it himself**

A CONTROL PERSONALITY

Above Dave Boyd's desk at Universal Oil Products Co. hangs a sign reading: "Livin' Caint Be Simple Enymore—They's Too Many Gadgets." If Dave's complaining, he's got largely himself to blame. For he exemplifies the do-it-yourself rage that is turning so many American basements into diversified factories.

Dave's hobbies started running wild shortly after he graduated from the University of Colorado in 1941 with a BS in chemical engineering. While working for the Barret Chemical Co. in Philadelphia, he pieced together a TV set which, he recalls, "worked like a charm." This sparetime pioneer achievement earned him a transfer to the instrument department and headed him toward a brilliant career in control engineering.

The "Little Bulldog" guesses he'll have to stop fixing up his home

Shortly after joining UOP six-and-a-half years ago, the "Little Bulldog"—as his friends call him—designed his own home in Clarendon Hills, a Chicago suburb. With Dave doing his own general contracting, ground was broken in June. He, his wife Louise, and their boys Garry and Owen moved in on Christmas Eve. (Since then, they have added a girl, Barbara.) Even after six years, Dave feels they are still not settled. "I'm always making some improvements that boost my taxes way up. I guess I'll just have to stop fixing up my house."

A 10-by-14-ft greenhouse is another of his construction projects. In it he grows everything from tomatoes to orchids. So that the orchids would thrive, he installed temperature and humidity controls. This made his greenhouse a proving ground for the controls later put on a UOP Platforming unit at the Rock Island Refining Corp., the first refinery unit to be controlled wholly electronically.

Dave is a railroad tycoon— in his basement and back yard

Dave's 70-by-25-ft basement is a hobbyist's paradise A scale model railroad—¼ in. to a foot—takes up one corner. Outdoors, in his spacious back yard, Dave and son Garry, now 10, are building a steam locomotive, 5 ft long and kerosene fuelled. They were afraid to try it in the basement, because as Dave says: "I don't want to burn the house down."

Dave patches Albert's wise but battered face

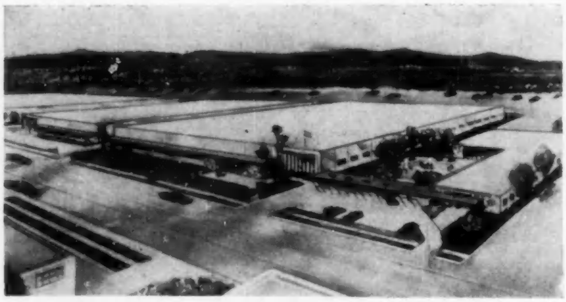
Another corner of the basement is an electronics lab, jammed with extensive equipment, all homemade from war-surplus parts. A partial listing: oscilloscope, vacuum-tube voltmeter, "Q" meter, sweep generator, capacity bridge, tube tester, audio signal generator, wheatstone bridge, grid-dip meter.

Out of this welter have come other gadgets that festoon the house and grounds. In the living room, Dave relaxes with his own hi-fi phonograph and 16-in. television set. One of his pets is a device that opens the garage door when he pushes a button in his car.

Dave is enthusiastic about his gadgets. But when he speaks of "Albert," a note of reverence creeps into his soft voice. Albert is an electronic analog computer, made from war surplus materials and capable of performing ten mathematical operations simultaneously 60 times per second. The computer is named after Einstein, who, as Dave puts it, "was good at math, too."

Albert was conceived from Dave's private notions

(continued on page 92)



Ramo-Wooldridge's monument to its future

Columbia-Southern's low, long lab for control research

Building Boom Marks Control Expansion

New Plants Aplenty Going Up From Coast to Coast Feature Long Low Lines, Lots of Windows, and Ample Floorspace for Growing Personnel

Control firms ready for new work and research, firms expanding from other fields and firms newly created for controls are occupying new houses across the country. Here is how the building circuit appears in detail:

▶ Ramo-Wooldridge Corp., a year-old Los Angeles electronics firm, has started work on a 150,000 square-foot plant addition. It represents a $1,750,000 investment to handle expanding work in computers and missile control systems. In its year of existence, Ramo-Wooldridge has accumulated order backlogs amounting to $4,000,000. It also has accumulated a staff of 150 persons. When its new quarters are ready, however, 1,000 will be the payroll figure.

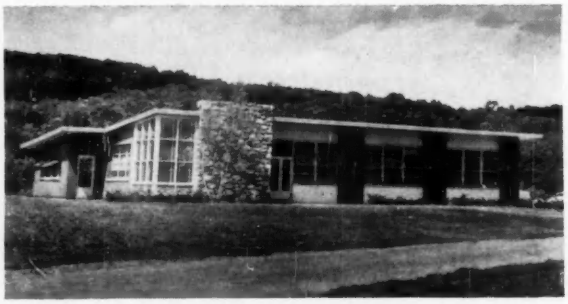
Founders of the firm are former Hughes Aircraft Co. executives, Dr. Dean Wooldridge, president of the new firm, and Simon Ramo, vice president and executive director. They are not, they say, competing with their old employer. In fact, an official said, they'd "like to bury the past relationship." To help them forget, Gen. Harold L. George, former vice president and general manager of Hughes, is on hand with the new firm as administrative consultant and board member.

Another mark of the firm's expansion: recent announcement of the founding of a wholly-owned subsidiary. Pacific Semiconductors, Inc., to develop, make and sell advanced diodes and transistors.

▶ Lockheed Aircraft Corp., a California name of some years standing, has appropriated $10,000,000 to set up a new laboratory for advanced research by its Missiles Systems Division (hard at work, paradoxically, outmoding the company's other martial products). Nuclear research, according to Elwood R. Quesada, former air general and now a Lockheed vice president, will be stressed in the new lab. A nuclear physicist, in fact, will head the new lab organiaztion: Dr. E. H. Krause. The physicist, however, has had wide exposure to control systems both at Los Alamos and at the Naval labs in Washington. And, Quesada made clear, the new lab will be involved in research on entire missile systems; the guiding, the "going," and the explosive goal.

▶ Donald P. Mossman, Inc., manufacturers of multiple-circuit lever, turn, and push-button switches, is moving and growing at the same time. All manufacturing facilities are being transferred from Joliet, Ill., to wooded, modernistic quarters at Brewster, N. Y. All sales and administrative functions also will be at Brewster. The new plant, on a 9-acre plot, adds both to the firm's present productive capacity and future ability to expand.

▶ Telecomputing Corp., of Burbank, Calif., maker of sales sorting machines, has picked out a San Fernando Valley location for a new 50,000-sq-ft plant. Estimated to cost about $430,000, the plant will begin building this month, is expected to be completed by year's end, and will house 500 persons. What they'll be working on is the company's "Point



Mossman moved its work to Brewster

Brew & Co.'s delay-lines plant and lab

o' Sale Recorder," an automatic recording device that handles data for inventory control.

▶ Columbia-Southern Chemical Corp., headquarters in Pittsburgh, will channel its process-control research through a new laboratory construction project. The firm has awarded contracts for two lab buildings at Natrium, W. Va. One will house control and fundamental research work. The other will take care of development and pilot plant operations.

▶ Richard D. Brew Company, designers and builders of delay lines, expects to get quite promptly into its brand new plant at Airport Road, Concord, N. H. This month is the target date. The new plant, right next to the Concord Airport, will not only expand the firm's production facilities but will provide a fully equipped electronics lab for testing delay lines and associated components.

Instrument Congress and Exposition Get's Ike's Blessing and Its Own Law

A month before the First International Instrument Congress and Exposition opened in Philadelphia, the U. S. Senate gave it an official boost. At the urging of Sen. James Duff of Pennsylvania, his colleagues passed a bill authorizing President Eisenhower to extend invitations to representatives of all states and foreign nations of the free world.

This was the second time Congress had taken note of the Instrument Congress. A couple of months earlier, Public Law 481 was passed. In ordinary language its provisions were:

1) Any article imported for the exposition comes through customs duty-free.

2) If any of these articles are sold, the Treasury Department collects duties. If it has deteriorated, the tariff applies to the reduced value.

3) Any time up to three months after the exposition closes, the importer can still duck the duties by destroying the stuff under customs supervision or abandoning it to the U. S. Government. If meanwhile he has sold the article, the Treasury will refund the money it collected.

Two Engineers Rival Hollywood

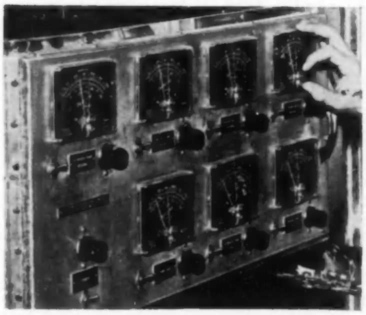
When Shell Oil's Wood River-Chicago Multiple Products Pipeline got running last December, two of the engineers who had nursed the project celebrated in a strange way. They made a movie that describes their work.

The co-producers were: Syd Smith, recently retired from managing Shell's Products Pipeline Department; and Rudy Lowe, president of Proportioneers, Inc., the company responsible for the blending controls. Smith banged out a fast-moving, 108-scene script and, in his deep, relaxed voice intoned the narration, which soundtrack engineer Lowe recorded. Lowe also furnished some of the cameras. And both men took turns at shooting.

Smith and Lowe are inclined to wry grins and knowing chuckles when they look back at their seven hectic weeks as movie moguls. Amateurs though they were, they worked out one time-saving technique worthy of Disney. Instead of laboriously stringing cartoons to get animation sequences, they built mechanical models of pipeline equipment.

Action shots of these models plus scenes filmed in the field make a well-paced half-hour movie for engineering audiences. It shows, for example, how controlled blending equipment adds TCP, tetraethyl lead, and several other compounds to pipeline products.

Copies are scarce, but the film is available for booking by private groups through Proportioneers, Inc., 345 Harris Ave., Providence, R. I. As this issue of CONTROL ENGINEERING went to press, Proportioneers announced they would run the film at the First International Instrument Congress and Exposition.



Safety trip point is set from face of meter

Stopping Bearing Burnouts On Land as on the Sea

Whether you're operating a string of pipeline pumping stations or a marine engine room you still have to worry about possible machinery breakdown because of overheated bearings. With this in mind, two companies have developed new temperature-sensing systems that make it easy to check bearings in these applications.

On land–A Simplytrol Polypoint, manufactured by Assembly Products, Inc., monitors all critical bearings in a pipeline station and shuts down the station when a "hot" one turns up. Temperature sensing is done with an iron-constantan thermocouple attached to each bearing. Readings show directly on a meter scale, with a safety trip point set just above the normal operating temperature (see cut). Excessive temperatures close a meter-relay, shutting down the station. Other controls actuate valves to immediately bypass the station and signal the shutdown to a central control point.

Cost is about $100 per bearing or less, exclusive of installation.

This system has been installed in the Twinsburg station in northern Ohio, part of a pipeline network interconnecting several refineries. It is completely automatic and runs unattended. All instruments and controls are isolated in a separate building 300 ft from the pump house to prevent possible explosions.

On the sea–Thermistor sensing elements and transistor amplifiers monitor as many as 40 bearing temperatures in a ship's engine room. Developed for the U.S. Navy by the Minneapolis-Honeywell Regulator Co., this system continuously scans all critical points. When a bearing gets "hot", an alarm sounds and a signal light glows to locate the trouble. By flipping a switch, the operator can get a temperature reading.

Since most of the critical bearings are on the main drive turbines, pre-

vious intermittent scanning systems were unsatisfactory. Fatal "burnouts" could occur between temperature checks, particularly under battle conditions when an unusual strain is put on the ship's engines.

When the Navy bought this system, it got a bundle of new techniques. The transistor amplifiers are one-third the size and one-tenth the weight of comparable vacuum tube units, and draw about one-tenth the power. The first naval use of thermistors reduces the required auxiliary equipment. Printed circuits instead of complicated wiring arrangements cut production costs by reducing wiring time and human errors.

Important Moves By Key People

▶ Douglas M. Considine is now marketing director for P. R. Mallory and Co., Indianapolis maker of electronic components and metallurgical products. Well known throughout the control field, he was one of the early students of control engineering at Case Institute. Since 1950, Doug has had charge of the market extension division at Minneapolis-Honeywell's Brown Instruments Div., Philadelphia.

▶ Charles W. Bowden, Jr., takes over at Brown, replacing Doug Considine. Charley graduated from Lehigh, and after the war joined Honeywell. He has served as an industry engineer and as sales manager for the company's textile, power, and chemical industry divisions.

▶ J. F. Steigerwald is the new chief designer of G. M. Giannini's Corporate Engineering Div. in Pasadena, Calif. He is responsible for tooling, processing, and production design of instruments developed by the division. His background is: chief production engineer at Jack & Heintz; manufacturing manager of Aerojet Engineering Corp.; and vice-president and production manager of the Bill Jack Scientific Instrument Co.

▶ Jerome Corwin has joined the Special Products Div. of the I-T-E Circuit Breaker Co. There he will head a new design and development section on electromechanical devices, servomechanisms, and computers. While at the Signal Corps Laboratories, Fort Monmouth, N. J., Corwin designed the antenna for the first radar contact with the moon.

▶ Nat Magida will develop new applications for Sorenson & Co. voltage regulating equipment at Stamford, Conn. For the last six years, he has been chief applications engineer of the Electric Regulator Corp.

▶ Dr. Frederick E. Terman, dean of School of Engineering, Stanford University, has been elected to the board of the Ampex Corp. Other changes at Ampex include: Charles McSharry, from member to secretary of the board; Robert Sackman, manager of new instrumentation division; and Phillip L. Gundy, manager of new audio division.

▶ Albert Wiebe resigned from the U. S. Army HQ Quartermaster Corps, where he had been chief of the Instrument Engineering Office. He is now directing Albert Wiebe and Associates, consultants in instrumentation and automatic control.

Doug Considine moves over to Mallory as marketing director . . .

. . . while Charley Bowden moves up at Brown to direct market extension

Corwin, designer of moon radar antenna, heads new section at I-T-E

ATOMIC ITEMS:

Dean Starts New Company

Former AEC chairman Gordon Dean heads a new Pittsburgh company, Nuclear Science and Engineering Corp. As its name implies, the firm will do jobs for and give advice to companies stepping into the atomic energy field.

NS&E's president, Ronald A. Brightsen, who worked on atomic power development with Westinghouse Electric, has no worries about the future of his market. It is known, he said, "to embrace the entire chemical industry, steel, petroleum, glass, non-ferrous metals, coal, plastics, and pharmaceuticals, with applications in many other industries still unexplored."

In addition to Dean and Brightsen, the board of directors includes: Glenn T. Seaborg, University of California Nobel Prize winning chemist, and Manson Benedict of the Massachusetts Institute of Technology. American Metal Co., Ltd.; Ketay Mfg. Corp.; and Lehman Bros. hold stock in the new company.

Engineers Plan Meeting

The Engineers Joint Council is catalyzing a National Congress for Nuclear Science and Engineering, to be held some time in 1955. A general committee representing the engineering societies and several scientific societies will make firm plans. And pro-

Decitron

MODEL D1
Counts up to 20 units per second.
Other models up to 5000 UPS

Industry's most reliable electronic counter

S P E C I F I C A T I O N S

	MODEL NO.	MAX. SPEED	REGISTER RECORDS ON EVERY	RESET
STRAIGHT	D1	20/second	10 counts	by hand
	D1-12	20/second	12 counts	by hand
	D2	200/second	100 counts	by hand
	D2-144	200/second	144 counts	by hand
	D3	5000/second	1000 counts	by hand
PRESET	P2	60/second	number set	automatic except register
	P3	60/second	number set	
	P4	60/second	number set	
WARN'G	PW2	60/second	number set on upper control knobs (warns on number set on lower controls)	automatic except register
	PW3	60/second		
	PW4	60/second		

NOTE: The last category also adaptable as lineal footage counters.
Currently in development stages is a new type of electronic relay which will only contain one tube, but will permit slow range counts up to 2 per second. The totalizer will register on direct impulse as the objects pass through the photo head.

Reliability in all kinds of counting operations . . . The Post Decitron eliminates costly production oversights and allows a continuous check of product total.

Available models cover every counting need from slow speed direct counting — to amazing totals of 6000 units per second.

Preset counters permit desired total counts i.e. dozens, fifties, gross lots, etc. Warning systems can be energized by special preset models to slow down or stop machinery, sound buzzers and perform a variety of helpful functions. Lineal footage counters measure production of paper, cloth etc.

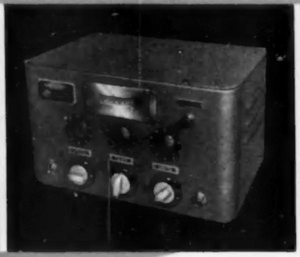
You can save production losses with compact, inexpensive, Decitron electronic counters.

MODEL D-2-144
Double Decitron with 12 place tubes. Counts gross lots

MODEL P2
Counts in any desired total 1-100
Other models 1-1,000,000

MODEL P3
Preset counting any number 1-1000 inclusive

MODEL PW4
Desired count from 1-10,000 plus wired in warning system



ELECTRONIC PRODUCTS DIVISION

POST MACHINERY COMPANY

Beverly, Massachusetts

gram and publications committees will attend to other detailed work.

As now envisioned, the Congress will be technical but will be open to everyone. Aftermaths will be probably a book of published papers and possibly a monthly magazine.

AEC Reports to Nation

The frightening prospect of a runaway may be only a nightmare—at least, in the case of one kind of atomic pile. In its Sixteenth Semi-Annual Report, the AEC reveals that the Argonne National Laboratory reactor shuts itself down before its power gets out of hand. The Argonne pile, both cooled and moderated with water, was allowed to run wild in an experiment. Some atomic savants had assumed that the core would melt and let loose dangerous fission products. To the contrary, as the power rose to thousands of kilowatts in a fraction of a second, the steam squelched the nuclear reaction.

Other atomic developments with instrumentation and control aspects:

▶ Another experimental breeder reactor planned by Argonne. While creating fresh plutonium, this pile will generate 15,000 kw of electrical energy and the equivalent of 62,500 kw more of heat.

▶ A revolutionary thermocouple needle. It consists of a copper-nickel-manganese wire wrapped around an Inconel tube. Such instruments, .040 in. in diameter and 20 ft long, have been jockeyed through tiny, winding cracks to measure temperatures as high as 1,250 deg F.

▶ A faster-acting neutron counter. Developed at Argonne, it is a scintillation counter filled partly with methyl borate. When a boron nucleus captures a neutron, a flash of light indicates a count to photomultipliers.

A Fresh Look at The Automatic Factory

What would be one of the least likely directions a businessman could turn to get down-to-earth answers on control engineering? To a group of young Harvard students, untried in business, unsure of their futures, and with no thought of doing control engineering work. Yet just such a group has provided one of the clearest answers so far to the pertinent, hard-headed question: "just what does control engineering mean to me?"

The students, seven in all, jointly authored a new report on "The Automatic Factory." All were candidates for the Master in Business Administration degree. They worked on the report as part of the requirements of the manufacturing course of Georges F. Doriot at Harvard Graduate School of Business Administration.

Actually, it was quite probably because of their lack of background in the field that their report turned out so successfully. The manufacturing course requires definitive industrial reports by groups of students. When this part of their study came around, the seven already had decided to work together. Rather than pick a specialized topic, however, they wanted one of general manufacturing interest. Control engineering seemed a natural. Automatic factories, they reasoned, would have the most profound general effects imaginable on manufacturing processes. And at just that point their advantages over researchers who might have an extensive background in the subject became apparent. The seven had to search out their answers from the most elementary beginnings. They did not fret with daydreams. They had to know realities. Very carefully they went hunting for the forest. It took them well over a half-year of travel, talk, and reading before they even worried about the trees.

Their preface spells out the matter-of-fact objective: "This report attempts to bridge the gap between the theoretical concepts and the actual industrial developments. It has been written principally for the American businessman in an attempt to clarify and expose the sometimes hypothetical and imaginative writings of scientific and commercial authors. Dreaming and guesswork has been purposely omitted . . ."

Another kind of automatic pipeline in Mexico:

Set up by a team of Italian engineers, the TAMSA pipe factory between Mexico City and Vera Cruz relies heavily on controls. This picture shows one of the panel points in the extensive control engineering setup built into the plant. Ingots are fed into the plant, heated, punched, drawn, re-heated, cooled, cut, and fed out for storage or shipping—all without being touched by a hand. Because of the extensive automaticity, foreign technicians were able to go home almost immediately. The plant now uses 100 per cent native labor and skills.

At the outset, the group shows how firmly it means that. Putting the automatic factory in perspective, they discovered, meant realizing that two manufacturers might have totally different ideas even of what an automatic factory (or automaticity, as the authors prefer) means. To a materials-handling manufacturer it would mean automatically moved items. A machine-tool point of view, however, would have it mean automatic machining. Actually, the authors point out, the conflict doesn't lie there at all. It is buried in the basic disagreement over whether present day technology, particularly that involving electronic selection, is adequate to setting up an automatic factory.

The report's researchers decided that an evolutionary process will lead to the automatic factory—rather than a revolutionary process. One example is the machine tool operating so swiftly that its human operator is no longer able to adjust its controls. Thus some automaticity is needed, and the plant is one step closer to being "automatic."

The Harvard students did not get their answers easily. First, they sat down and read basic books on the subject. They discarded all the fanciful or vague material but paid particular attention to names mentioned in both texts and bibliographies. Then they started writing to these names. Back came 24 extensive replies on various phases of control engineering. Both the research and the applied points of view were represented. Examples of their respondents: Atwood Vacuum Machine Co.; DuPont; Detroit Broach Co.; Bureau of Standards; Esso Refinery; Ford Motor Co.; General Motors; Jones and Lamson Machine Co.

For solid, face-to-face questioning, they had audiences with such men as Dr. Donald Campbell of M.I.T.; Detroit motor company officials, and Nelson Gilersteine right at Harvard.

Largely because of this plugging approach, they bring really informative clarity to chapters on: Mechanization vs The Automatic Factory; Obstacles; Contemporary Automaticity (in automobile and four other plants); Costs; Social Implications. Also included is a generally valuable manufacturing cost determination of "Project Tinkertoy," the famous ceramic-wafer, printed-circuit development.

The group who did the job: Stephen A. June, the project's coordinator and a hopeful in the line of production supervision or industrial product sales; John D. Bardis, who wants to go into merchandise planning and control; Lee Lurio, a Yale graduate with no definite job goal at this time; Leonard S. Polaner, whose training has emphasized production and marketing; Oystein Sagedahl, raised in Norway and now aiming toward production supervision; Herbert Sklenar, also a production man, and Bernard Yenkin, another production supervision student.

Prospects Are Bright For Smell That's Right

How can you apply feedback control to something you can't measure? You can't. That's what disturbs engineers in the food industry, who want to regulate flavor and odor automatically.

Odor measurement has finally reached the distinct-possibility stage, judging from a paper presented as this issue went to press at the American Chemical Society's national meeting in New York. Robert W. Moncrieff, a consultant from Girvan, Scotland, reported experiments on the adsorption of odorants.

According to one theory, your smell sensation depends on the way nerve terminals in your nose adsorb tiny amounts of vapor. Dr. Moncrieff confesses: "It is not practicable to use those adsorbents which occur in the olfactory area." But in working with such common adsorbents as carbon and silica gel, he has found that odor quality and adsorption characteristics correlate closely. Thus some sort of adsorption meter could conceivably be the sensing element for automatic odor control.

The day may come when restaurants advertise "Automatic Cuisine," or a perfume manufacturer can set a potentiometer to "Channel No. 5."

Patent Board Announces Instrumentation Book

Dr. Archie M. Palmer, Chairman of the U. S. Government Patent Board, has announced the release of a new book listing 775 Government-owned inventions in the field of instrumentation. In addition to an abstract, each listing includes the patent number, the title of the invention, the inventor's name, and the Government agency administering the invention. Applicants to the indicated agency can get licenses to use the inventions royalty-free.

Here are some examples that indicate the practical value of the book: a humidity measuring device, a remote-control manipulator, and a carbon dioxide detector.

To help readers locate interesting items, the listings are broken down into eight subgroups:

- ▶ Laboratory, scientific, engineering
- ▶ Instruments for indicating, measuring, and recording electrical quantities and characteristics
- ▶ Mechanical measuring and control
- ▶ Optical instruments and lenses
- ▶ Surgical and medical
- ▶ X-ray and therapeutic
- ▶ Surgical and orthopedic appliances and supplies
- ▶ Photographic equipment, supplies

Geologist's "Road Map" Plotted Electronically

Seismographic data, collected by field crews of major oil companies and geophysical exploration outfits, are now being analyzed by new electronic data-reduction machines and high-speed digital computers, a technique that may help to extend the petroleum reserves of the United States and other countries.

Experts estimate that some $2 billion a year are invested in the search for oil both on land and in coastal waters. Much of this huge sum goes into seismic exploration, which consists of studying the results of controlled man-made earthquakes. An explosive charge is set off at a point below which the presence of oil is suspected. The echoes of this explosion, from reflecting layers or geological formations down to 20,000 ft. below the earth's surface, are received by sensitive geophones and recorded on oscillographs.

In the files of major oil producers and geophysical exploration companies are tens of thousands of these oscillographs, records of earthquakes man-made in the hunt for oil. Until recently these oscillographs have been analyzed by laborious manual methods, reading points on the curves, writing down the data, and then doing complex calculations. The results are then plotted by draftsmen to show a picture of the earth structure below the point where the field crew exploded a charge. This plot then be-

comes a geologist's "road map" in determining where to drill for oil.

The new electronic technique consists of using an OSCAR oscillograph reader and analyzer, and an Electronolog digital voltmeter, machines made by Benson-Lehner Corp., Los Angeles. With this equipment, the information on the seismic records is quickly and accurately converted into numerical form, and these numbers are then fed automatically on punched paper tape or business machine cards into various types of high-speed digital computers.

These computers perform computation, and then they feed the results into a Benson-Lehner Electroplotter, or automatic plotter. Here the underground picture that the petroleum geologists want is speedily and accurately plotted.

It is estimated that these new electronic techniques make it possible to obtain more accurate geological information in less than one-fifth the time formerly required.

For Computers and Captains, Standardized Sea Miles

Possible confusion, for man and machine alike, over just how far one (or it) travels when going a nautical mile, has been precluded by the recent adoption of the International Nautical Mile by the National Bureau of Standards. Previously, the Bureau had used the slightly longer U. S. Nautical Mile, while a good many other labs in a good many other countries were using the International. Here are the differences: The now replaced U. S. Nautical Mile has a length of 1853.248 meters, or 6080.20 feet. The International Nautical Mile (in use by the International Hydrographic Bureau since 1929) is 1852 meters, or 6076.10333 feet long. The Bureau of Standards action confirms an agreement between the Secretary of Commerce and the Secretary of Defense to use the International Mile in their departments.

Honeywell Contract Points To 'Shocking' Upper Air

The Air Force, looking upward as usual, now hopes for more and better answers about the electrical currents existing between the earth and space 100,000 feet above it. To help get the answers it has given Minneapolis-Honeywell Regulator Co.'s Industrial Division a $15,000 contract to produce an undisclosed number of "aerial electrometers." The units were designed in the company's Philadelphia nuclear engineering labs and are described, not very graphically, as supersensitive electronic devices. The Air Force's gadget was designed for a continuing study devoted particularly to the "terrestrial electrical field" existing between the earth and ionosphere (which begins 60 to 80 miles up).

Philadelphia IRE and AIEE To Sponsor Symposium

Latest symposium on automatic production in the electronic, metalworking and process industries will be sponsored by the Philadelphia sections of the AIEE and IRE. Meetings will be held one night a week from October 14 until November 18.

The topics to be covered include: automatic production in the automotive industry, automatic fabrication in the electronics industry, automatic wiring, etched circuits, flexible control of electronic assembly, the modular approach to mechanized assembly, instrumentation and the analog computer in process control, important developments affecting automatic production in chemical plants, and the economic and management aspects of automatic production.

Speakers will include: Cleo Brunetti of General Mills; J. E. Cunningham of Wilson Automation Co.; Semi J. Begun of Clevite-Brush Development Co.: Donald Mackey of Radio Corp. of America; George W. Gamble of General Electric; Robert F. Henry of American Car & Foundry; Prof. Donald P. Eckman of Case Institute; and Victor F. Hanson of Du Pont.

Details about this series of meetings can be obtained from Mr. S. E. Moore of the Philadelphia Electric Co.

"That kid of mine is a beautiful servo—15 pounds of him lets out a peep and 200 pounds of me gets up for a glass of water."

RESULTS OF AN INTELLECTUAL REVOLUTION . . .

"The Western Miracle" Continues... More Automatic Controls for Industry

Within recent weeks three new monthly technical magazines devoted to automatic control systems for industrial processes and machinery have offered the public their first issues. One of these is CONTROL ENGINEERING, a McGraw-Hill publication.

What has caused this surge of interest in the design and application of automatic control systems? What does it portend for the future of American industry? More important, what does it promise for the American standard of living, of which industry is and must be the servant? And what is the role of CONTROL ENGINEERING in this development? It is to those questions that this statement is addressed.

A New Intellectual Revolution

It is frequently asserted that we are now in the throes of a new industrial revolution. The revolution is described as the eliminating of wasteful applications of human labor to repetitive tasks through new technology which makes it possible to transfer those tasks to automatically controlled machinery.

It is perhaps more accurate, however, to say that we are the beneficiaries of a new intellectual revolution in the application of science to industry. This new intellectual revolution points the way toward giant strides in the continuing process of taking dull and laborious work off the backs and minds of men and transferring it to machines operating in large batteries under automatic control.

The practical engineering work required to convert this intellectual revolution into a full-scale industrial revolution, however, in large part still remains to be done. It is to this task that CONTROL ENGINEERING will be devoted. Its role is that of bridging the gap, in engineering and economic terms, between the new conceptions of automatic control of industrial processes and their practical workaday application. These conceptions run the full gamut from systems of control for automatic factories making heavy industrial products to highly personalized systems of automatic control to warn people when they are approaching the broiling point in sunning themselves at the beach or becoming too drowsy to drive their cars safely.

Enter the "Feed-Back" System

Enough work has been done to move these conceptions out of the realm of interesting dreams and into the realm of practical possibilities, and in some cases into the realm of practical realities. Crucial parts of this work were done during World War II when weapons were successfully equipped with "feed-back" systems

that automatically corrected mistakes made by the weapons in locating their targets.

The principle of the "feed-back" system is as ancient as the personal monitor that tells us not to run into each other as we walk along the street. It feeds back to our locomotion machinery the warning of a collision ahead. But the application of the principle to weapon control and then to more general machinery control required superlatively imaginative and skillful scientific development.

When a "feed-back" system that monitors an automatic process and keeps it lined up precisely is teamed up with a computing machine, capable of making lightning calculations that control both what goes into the process and what is done with the product, the horizons of automatic control become broad indeed. But in large part they still remain horizons. A vast range of practical engineering work remains to be done to realize anything like the full potential of automatic control of industrial processes and machinery.

More and Better Jobs

There are those who view the surge of interest in automatic control with alarm. They conjure up a situation in which automatic processes will at once expand the ranks of the unemployed and reduce many of those still working in industry to the status of robots or automatons.

A look at the record of the American economy — a record of amazing growth, steadily improving job opportunities and a constantly rising standard of living — demolishes the basis for such fears. The introduction of new and more efficient industrial machinery and processes obviously cannot be accomplished without creating some disturbance for some individuals and some companies. But consistently the longer range effect of such local and temporary disturbance has been more jobs and better jobs for Americans.

It is no accident that, while the proportion of industrial wage earners in our population is virtually the same as it was in 1920, the proportion of professional and salaried workers has doubled. The proportion of unskilled workers, furthermore, has dropped by half. This has been an essential part of a continuing process by which drudgery has been transferred to machines while the workers who formerly did the drudgery have been graduated to jobs calling for greater competence and providing better pay.

Higher Living Standard

A British historian, H. J. Hancock, has referred to this general process as "the Western miracle"—that of providing an ever higher and higher standard of living for more and more Americans. The key element in this miracle has been more and more reliance on power-driven machines to get the day's work done.

In the nature of the extremely complicated apparatus involved, full development of systems which have passed through the "think stage" into the status of practical possibilities will be a time-consuming process. It will also be a very exacting process, calling for a tremendous application of engineering skill and ingenuity. However, the engineers who are concentrating on this difficult, workaday phase of the development of apparatus for automatic control will be inspired by the knowledge that they are making a crucial contribution to technical progress which holds great promise of good for the American people.

This message is one of a series prepared by the McGraw-Hill Department of Economics to help increase public knowledge and understanding of important nationwide developments that are of particular concern to the business and professional community served by our industrial and technical publications.

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Donald C McGraw

PRESIDENT

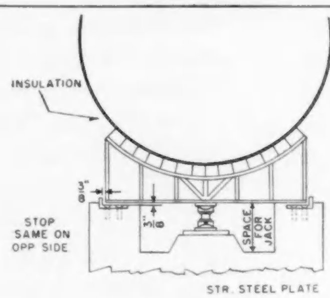
McGRAW-HILL PUBLISHING COMPANY, INC.

Let us take a load off your mind!

DO YOU have a tricky load measurement problem on your mind? Something like measuring the tension on a conveyor belt for example, or the thrust on a bearing, or the weight of solids or corrosive liquids in a tank . . . ? Taylor volumetric load measuring elements have been used for years in paper mills, but there are many applications throughout the industry where these highly accurate and sensitive instruments are proving invaluable. Most recent developments afford a wide variety of ranges, greater range suppression, greater over-range protection and greater energy for positioning the pen or actuating a control mechanism. Applicable to tension and compression loads. Call your Taylor Field Engineer or write for **BULLETIN 98232.** Taylor Instrument Companies, Rochester, N. Y., and Toronto, Canada.

PROBLEM — **SOLUTION** — **CHARACTERISTICS**

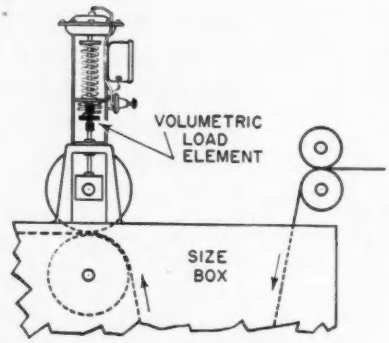
To accurately measure the weight of chlorine in tanks



Spool type Load Measurement Element

Range limits: 0-240,000 lbs. for compression loads, maximum load not to exceed 400,000 lbs. Applicable to horizontal or vertical tanks, containing corrosives or solids, making conventional level measuring devices impractical. Tension loads 0-30,000 lbs.

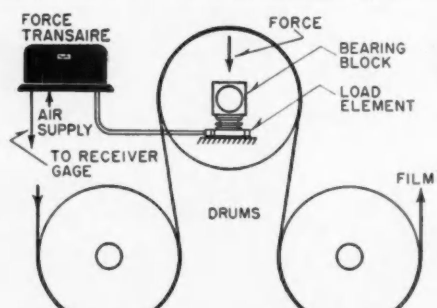
To accurately measure squeeze roll pressures on textile slashers



Diaphragm type Load Measuring Element

Range limits: 0-5,000 lbs., maximum load not to exceed 6250 lbs. Compound ranges, tension—0—compression also available. Applicable to measure roll or nip pressures in calender stacks, press section and many other finishing operations involving processing of material between rolls.

To measure film tension within very close limits as a measure of "gain" or percentage of stretch



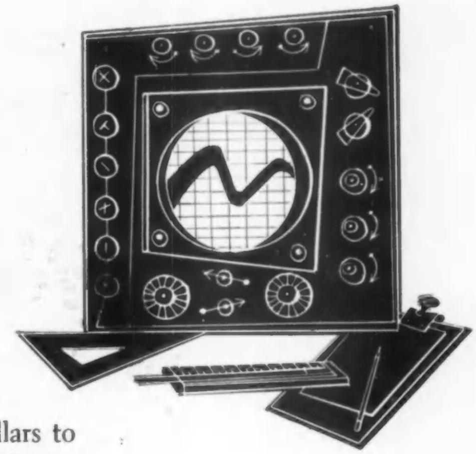
Transaire Volumetric Load Measuring Element

Range limits: 0-300 lbs. in range spans as short as 30 lbs. Used in conjunction with a TANSAIRE* Pressure Transmitter which sends an output air pressure to an indicating, recording or controlling receiver proportional to the force applied. Applicable to film, paper, yarn or similar tension measuring requirements.

*Reg. U.S. Pat. Off.

TAYLOR INSTRUMENTS MEAN ACCURACY FIRST

Industry's Pulse



Suppose you have a few hundred or a few thousand dollars to invest. Do you have enough confidence in control engineering to bet on its future? Where would you put your money—in the companies who use automatic processes, or those who manufacture instruments and controls?

More and more brokerage houses and security analysts are asking these questions. Several have assigned staff members, full time, to keep tabs on control and evaluate its investment potential.

Control Specialists on Wall Street

Generally, these specialists agree that control engineers are piloting an outstanding growth field. Some of the stocks may not yield fat dividends now, but their value seems sure to increase. The professional judges of investment must decide just where they and their clients can make money, how much, and how soon.

One of the reports they are studying closely is the Stanford Research Institute's recent survey of the electronics market. SRI finds that factory sales of data-processing equipment soared from absolutely nothing in 1940 to $25 million in 1953. The current trend? Almost vertical, in SRI's opinion, pointing to $500 million in 1960. Electronic instruments for industrial control project the same bright picture: $3 million in 1940, $65 million last year, and probably $150 million in 1960. Add in the machinery that goes with the instruments, and by itself the electronic end of control engineering will be a billion-dollar field.

Electronic Controls: Vertical Trend

In midsummer, one New York brokerage house finished a study of a thriving young California company that specializes in electronic instruments and computers. While recommending the stock to their customers, the analysts declared: "The real growth in electronics will be in process control."

The research department of one of Wall Street's biggest firms is now distributing a four-page summary of automatic control companies. It starts by expressing general enthusiasm for the prospects of control, particularly for data processing and electronic industrial control.

Most of the space, however, goes to an analysis of 38 stocks—what they are selling for now, last year's price range, earnings, and

<u>One</u> flow control does the work of nine

Denison Multi-Range Flow Control Infinitely adjustable for any delivery without changing spools

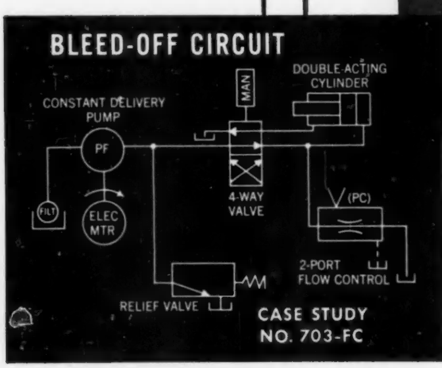
One dial now controls flow in as many as nine different ranges . . . an accurate, inexpensive means of controlling speed on hydraulically operated processing machinery.

With Denison Multi-Range Flow Control, there's no need to change valves or spools. If pump delivery is changed, simply turn the dial.

Available in 1/4, 3/8 and 3/4-inch port sizes. For any circuit to 3000 psi. Capacities to 28 gpm.

Subplate-mounted, Denison Multi-Range Flow Controls come in 2-port and 3-port types . . . with or without built-in check valves. The 3-port type meters flow to the work and diverts excess to tank.

The bleed-off circuit shows a Denison Flow Control regulating cylinder speed. For bulletins about Denison Multi-Range Flow Controls, write to: THE DENISON ENGINEERING COMPANY, 1170 Dublin Road, Columbus 16, Ohio.



PUMPS • MOTORS • CONTROLS • PRESSES

DENISON TRADE MARK HydrOILics

dividends. The analysts have broken them down into five manufacturing groups: data processing, electronic components, control instruments, machine tools and machinery, and miscellaneous. The list is nowhere nearly exhaustive. In fact, the analysts point out that some companies not yet in the field "may still have an opportunity to enjoy a vigorous participation in its development."

Fresh Chances for Newcomers

Not every company will strike gold in automatic control. How can you tell which companies will do best? Investment professionals are glancing back through history at earlier growth industries, including automobiles, radio, television, and chemicals.

The firm that is going to prosper has to be rich in basic technical knowledge, and it needs a sound, imaginative engineering staff. Exclusive control of important products and processes has given many of today's "blue chips" a jump on their competitors.

But it takes smart production and hard selling to turn products into profits. And only too often a promising company has failed because it lacked the financing for developing its ideas, getting into production, and weathering temporary setbacks.

The big company, fortified by previous success in some other field, has an edge over the little group that starts with an idea and piggy-bank capitalization. The established company can afford to pay for its research and development, and it can stand to lose money for a while. Besides, it has already built a reputation and a marketing organization. But the investor's dream is the rare shoestring operation that parlays the genius of a few engineers into a position of leadership. This is the company whose stock zooms ten or twenty times in value over a few years.

Some investment counselors are peering backstage at the people who buy controls and use them. The first company in any industry to make effective use of computers in its accounting, as well as to control instruments in its production, stands to gain a competitive advantage. In the next few years, control and computer manufacturers may not be able to keep up with their orders. And the companies that get equipment before the big rush begins will open a lead over their rivals.

One company which has ordered an extensive data-processing system is already sweating out delivery. The executives are convinced the equipment will save them several thousand dollars a month—money they are, in effect, now losing through the delay. This will be a familiar story for years to come.

Control
ENGINEERING
OCTOBER 1954

Our Profession Grows

As we see it, the people in control engineering are growing as fast as their field. The control engineer you should look for today has different qualifications from the man you hired ten years ago for control work.

Then, just as now, the man had to be familiar with the equipment he controlled. In aircraft design, he had to comprehend elementary aerodynamics and the principles of navigation. In a refinery, he had to understand the unit operations. If he wanted to control metal-working machines, he had to know his way around a machine shop.

A control engineer today has to know more about his "plant" than ever before. And he must know it in different ways.

First of all, he has to understand dynamics. Missile dynamics, machine dynamics, and prime-mover dynamics are well worked out. But few people know much about the dynamics of industrial processes, economic systems, or man himself.

Also, he must think in terms of systems. In the past, engineers analyzed plants by breaking them down into units and studying each as an isolated control problem. Today this is not thorough enough. The control engineer has to go one big step further. After he solves the individual control problems, he must, so to speak, put the plant back together again and make it an integrated control system.

The new approach to control makes cousins of all control engineers. No matter where each works, the common family strain is control-system dynamics. In this cousinship, we see the earmarks of a true profession.

Where are these new professionals coming from? Already 100 technical schools in this country teach at least one control-dynamics course to a total of 2,500 students.

And men who are past their schooldays can get help to enter the new profession. We will do our part. The technical societies are contributing enormously. Next April, for example, the ASME Instruments and Regulators Division will hold a conference on the dynamics of physical systems.

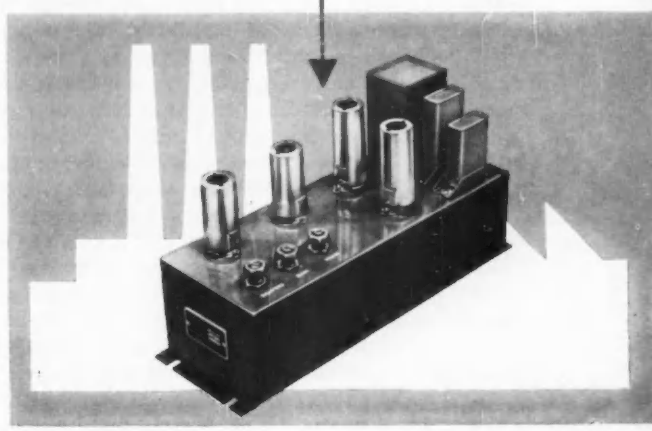
These combined efforts will continue to fill the ranks of our growing profession.

THE EDITORS

THE PROBLEM: How to switch from making this . . .

Leaner Markets Than You Think

. . . to making this



Here is an expert assessment of a quandary haunting hundreds of control manufacturers, large and small.

GEORGE M. ATTURA, Industrial Control Company

WHAT WOULD CUTBACKS MEAN?

Automatic control is no military monopoly. But the Armed Forces still absorb the bulk of the systems and components produced by the hundreds of companies in the precision-control field. The future of this whole new industrial complex may depend on the answers to five questions which every control company manager should ask himself:

- ►If military procurement were cut back, what new markets would I turn to?
- ►Could I sell at my present volume?
- ►Could I sell at my present price?
- ►Can I economize through company reorganization without courting business failure?
- ►Can I make a more salable product by trimming special costly characteristics the military demands?

Bewildered by the din of some prophets of automatic control, the manager may have a hard time deciding his answers. But two points are clear. Every company now selling primarily to the Armed Forces is looking for some industrial market. Yet at the same time, most segments of the technical press are loudly proclaiming the advent of the second industrial revolution with American industry reaching for all the automatic controls it can get.

Here is out-and-out inconsistency. If great markets for industrial control existed today, they would already be demanding, and getting, a much larger share of the control companies' output.

Elementary analysis clears up the discrepancy. Consider, for example, the precision 400-cps servomotor. Production of this motor in 1953 ran well over 150,000. At the moment, commercial aviation is the only likely nonmilitary market. A typical military airplane might have 30 servomotors; but a large commercial transport has only four or five. If the aircraft industry builds 200 new transports this year, it might siphon off 1,000 servomotors.

If Mr. X of Company Y has 3,000 servomotors to

dispose of in a competitive market during the next two years, he had better start work on his basic problem, market analysis and sales, and push aside those dreams of the digital computer that will run his office while he fishes his favorite creek.

Finding profitable new markets for firms manufacturing mostly military controls is a national problem. This group is under constant threat of a business recession resulting from military cutbacks. A whole new technology, developed over the last fifteen years, exists today only because of international tension. Its skills and products represent an extremely advanced scientific complex, whose potential contribution to industry is so novel as to be futuristic, and which the country can ill afford to lose.

The makers of control systems or components fall into four classes. Some make components used in other fields. Others produce equipment that indicates and controls such variables as pressure and temperature for the process industries. A third group specializes in speed and position controls for steel mills, textile looms, machine tools, etc. Their products may have benefited from engineering research and development sponsored by the military. But they have established industrial markets.

The fourth group relies almost entirely on the Armed Forces to absorb their output. Significantly, they are the companies which will contribute most heavily to the future expansion of automatic control, because for the last ten years they have been engaged in intensive system and component development to meet the increasingly stringent performance requirements of military devices. This military control industry now far surpasses the specialized groups feeding industrial markets, whether comparisons be made on total dollar volume, employment, technical activity, or number of units manufactured.

This is the group that must aim for new markets. These are the companies which must discover whether they can survive in the competitive atmosphere of industry.

WHERE ARE THE NEW MARKETS?

Many of the men who run these military control companies are so deeply engrossed in the elegance of their work that they fail to assess its future objectively. The basic mistake is to assume that industry will eventually control most of its processes automatically, and that the future control market comprises the bulk of American industry that has as yet resisted all efforts toward automaticity. The attitude of some is that industry must be "educated" to the blessings of automatic control, and that once this has been done, a tremendous market will be made captive.

To be sure, indoctrination through the twin media of company promotion and technical magazines will produce some effect. But again we must remember we are looking for markets to soak up 150,000 servomotors a year, not just the small outlets gained at an unrealistic price of promotion money and efforts.

The history of automatic control argues against the high-pressure-promotion approach. Those companies feeding the process-control industry expanded and prospered because the industry needed control, not because of the selling job their advertising may have done. Underlying all growth in the control field is this very important factor: the end user alone, and not the manufacturer, can evaluate the delicate balance between desirability and installation costs. Only the user can effectively compromise operational requirements with system simplicity.

Capital investment is the biggest deterrent to the new industrial revolution

Thus it does not follow, per se, that each machine tool should have a variable-speed drive and each commercial plane a navigational computer. Nor can we ignore a manufacturer's capital investment in equipment and technique. It is the biggest deterrent to the new industrial revolution—an upheaval which would force rapid obsolescence of equipment with a still appreciable working life. Many segments of industry will resist automatic controls for a long time to come.

In searching for new control markets, we must first examine those already established and discern their common features.

The military control field, undoubtedly the largest today, came into being because there was no other way of meeting equipment requirements. Demands for accuracy, response speed, and operation without human aid could be met only by precision controls built into self-correcting feedback designs. Invested "capital," represented by existing equipment, could prove no deterrent, and controls obsoleted much gear long before its time.

The second biggest field today is process control. One thing stands out: the process industries have expanded rapidly. The need for automatic controls has not been so urgent as in the military case. But the point is that when controls first entered the process industries, they had to shoulder aside few precedents, and the heavy capital investments were still to come.

A third market characteristic comes from a consideration of those who use positioning and velocity controls. They graft controls to existing equipment to increase productivity and improve products. Virtually every manufacturing industry is a potential customer. But oddly enough, this is the market that will require the hardest selling. Control equipment can be applied only when it is competitively necessary and where unavoidable scrapping of older equipment can be justified.

Thus, control makers should look for new markets in three categories:

1. Processes that won't work without controls.
2. New and expanding industries not already

crystalized by heavy capital investment.

3. Established industries where controls offer a competitive edge.

The first two situations represent the best present and future markets for control, whereas the third needs hard competitive selling. Yet the third, embracing all established manufacturing techniques, has been in many cases the only target of control companies seeking relief from a preponderance of military contracts. When looking for specific markets, we must look for new ones. For at present all the industrial control requirements are adequately filled by firms organized and developed for that purpose.

Atomic energy is the classic example of a process in which automatic control is absolutely necessary. It also fits the second category, for it is certainly expanding. In time it may be the biggest market for control.

The gradual absorption of controls by existing manufacturing processes should be neither overlooked nor overestimated. A steel mill built today is a marvel of complex control equipment, with positioning and velocity servo loops automatically regulating the processing of ingots, bars, and sheet. One new mill, however, does not obsolete ten older installations. The market must be geared to replacement rates.

Firms already in the process control and military equipment markets will probably handle the expansion in these fields. Also, we may expect some interplay, with many firms straddling both fields.

What of the new technologies just developing? A bold look is necessary to determine whether they fit into our pattern for a receptive market.

Electricity from solar energy may be a rich new field for automatic control

The astonishing announcement of a method for converting solar energy directly into electricity may foreshadow a rich new field for automatic controls. Unlike the steam- or water-driven power plant, the solar plant will have to cope with wide variations in available energy—the day-night cycle and short term fluctuations when clouds drift by. Only controls could assure regulated output power under these changing conditions.

The trend toward faster- and higher-flying commercial transports will require more extensive airborne controls. And some day in the not too distant future we may see guided missiles shuttling mail and freight between continents. Control techniques and equipment being developed today may take care of their immense problems of guidance, navigation, and power-plant control.

In contrast, rocket and space flight, when they arrive, will exploit all of today's most elaborate control techniques plus many yet to be developed.

The mere fact that a company recognizes potential markets does not assure it new outlets. A firm in the military control field may have grown up under subsidy of cost-plus fixed-fee, with all its facilities furnished by the government through tax amortization provisions or outright contracts. Such a company will have to adjust to a leaner market, and it may be hampered by an overload of administrative and engineering personnel.

WHAT REVAMPING IS NEEDED?

The personnel organization necessary for military work often needs revamping. A host of specialists, some of whom have no counterpart in industry, service a military contract. There is, for example, the contract administrator—an expert interpreter of the legal implications of the contract and the personalities of the military officer administering it. The standards engineer is an authority on innumerable military specifications, from types of vacuum tubes allowed to heights of lettering on shipping boxes. Their contribution to general administrative expense would add too much to unit product cost.

Products also may need basic revamping, if a firm is to switch from military control work to competitive manufacture. Many military controls are miracles of precision, built to rigid tolerances, and able to operate over extended ranges in any environment. But industry does not always need all these superb characteristics. It would be hard to sell an $80 servomotor to a factory superintendent accustomed to buying $\frac{1}{4}$-hp motors for less than $20.

Any firm considering a commercial market for its military control product must make a careful analysis of unit cost. Then it must decide where specifications and tolerances can be relaxed and what price industry probably will pay. One manufacturer has already taken this realistic approach and now offers a servomotor built and priced for industrial use, though designed partly from experience in military work.

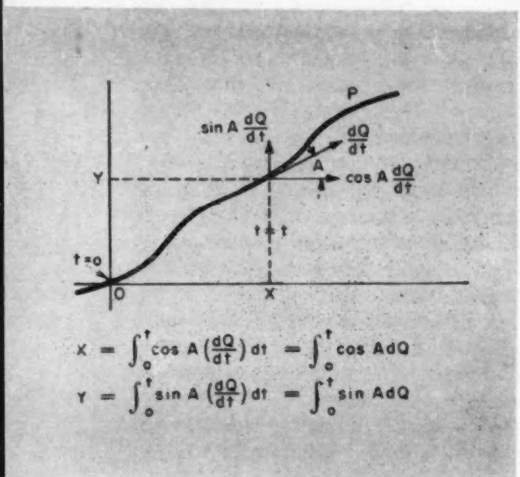
The problem of company reorganization crops up again. A group geared to a certain level of precision manufacture may not be able to achieve appreciable economies by lowering tolerances. Radically different production methods and new personnel with different skills may have to be introduced.

The transformation from military to industrial control manufacture may be difficult and perilous. But as these manufacturers grow, they will put new horizons of prosperity within the reach of all men.

AUTHOR ATTURA was born in Rome, Italy, and educated in the U. S. and abroad, receiving his BEE from Manhattan College and his MEE from New York University. After wartime service as a Navy radar officer in various theaters, he worked for Fairchild Camera and Instrument Co. and Servomechanisms Inc. In 1949 he helped organize the Industrial Control Company, Wyandanch, Long Island, of which he is chief engineer and general manager.

THE COMPONENT INTEGRATOR:

Can You Use an Unusual Computing Device?



One use of integrator, Fig. 1

THE GIST: Ball-and-disk integrators are commonplace in fire controls, navigational computers, and many other mechanical computing systems. A less familiar cousin is this spherical integrator. One roller spins the sphere. The speed and axis of rotation determine a particular mathematical function. Two other rollers "read off" the integrals —not of the function itself, but of its components paralleling the x-axis and y-axis. The spherical integrator is used in some navigational computers. But its peculiar properties should fit it for many other jobs. To help you find them, this article tells why this computer works, how it is constructed, and what it can do.

EDWARD BURGESS

Ford Instrument Co., Division of The Sperry Corp.

WITH TWO instantaneous inputs representing a velocity and direction of this velocity, the component integrator gives two instantaneous outputs corresponding to the components of the input velocity in two fixed reference directions. Thus it might be called an integrating resolver.

This is shown in Figure 1, where Q, is the distance traveled along arbitrary path *P* from time 0 to time *t*. At time *t*, the instantaneous velocity is dQ/dt in a direction determined by angle A. These are the two inputs to the component integrator. The two instantaneous outputs of the integrator are the components of the velocity, dQ/dt, along the X and Y axes: cos A (dQ/dt) and sin A (dQ/dt). Thus the total outputs of the integrator from time 0 to time t are equal to the X and Y coordinates of the curve at time *t*.

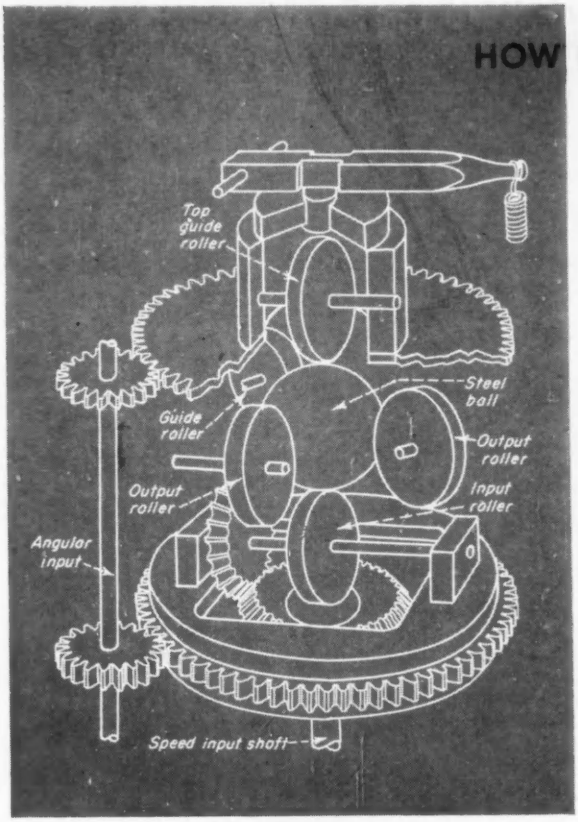
The operation of a component integrator, Figure 2, is based on the general rotational motion of a sphere. A steel ball is supported by five rollers. The input roller determines the angular velocity of the ball and the direction of this velocity. The output rollers deliver the two components of the input velocity. The top and side guide rollers are spring loaded and apply contact pressure. The input velocity is transmitted to the input roller through the bevel gear assembly, while the input angle is determined by rotating the entire assembly.

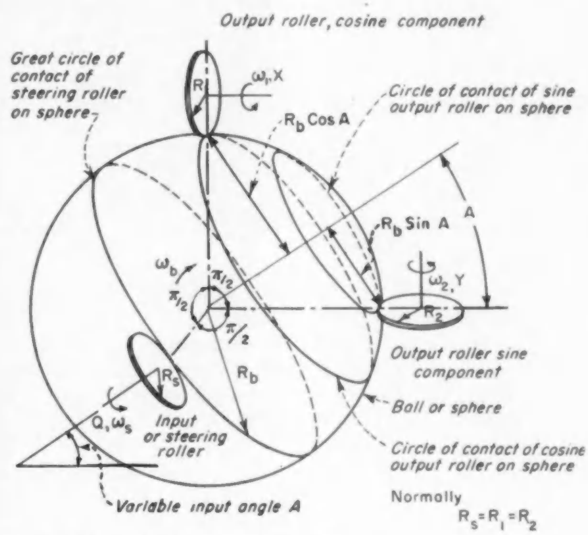
WHY IT WORKS

Figure 3 shows the geometric relationships for the integrator. The contact points of the three active rollers with the sphere must fall on an orthogonal set of axes with the origin at the center of the sphere. The resolver effect is apparent, since for any angle A the radii of the circles of contact of the two rollers are equal to R_b Cos A and R_b Sin A respectively.

Because of the mechanical construction of the component integrator (with A and Q being introduced as rotations about the same axis), a change in A will introduce a linearly related change in Q, while the normal Q input remains fixed. This can be seen in Figure 2. For the action to be theoretically correct, a cancelling correction proportional to A must be

HOW IT IS CONSTRUCTED





R_s = radius of steering or input roller

R_b = radius of ball or sphere

R_1 and R_2 = radii of output rollers

Q = angular displacement of input roller about axis

$$\omega_s = \frac{dQ}{dt}, \omega_1 = \frac{dX}{dt}, \omega_2 = \frac{dY}{dt}, \omega_b = \frac{R_s}{R_b}\omega_s$$

$$\omega_1 = \frac{R_b}{R_1}(\omega_b \cos A) = \omega_s \cos A, \ (R_1 = R_s)$$

$$\omega_2 = \frac{R_b}{R_2}(\omega_b \sin A) = \omega_s \sin A, \ (R_2 = R_s)$$

$$X = \int \cos A\left(\frac{dQ}{dt}\right)dt = \int \cos A\, dQ$$

$$Y = \int \sin A\left(\frac{dQ}{dt}\right)dt = \int \sin A\, dQ$$

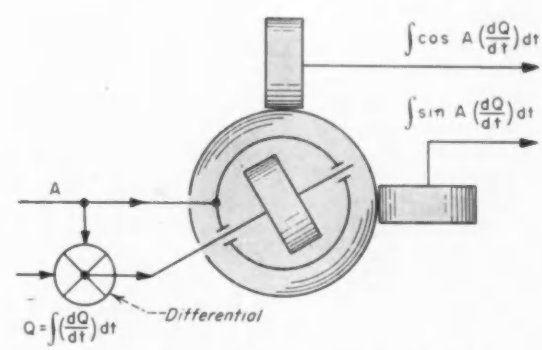
Cutaway diagram and functional schematic of the integrator. Rollers don't side-slip. Figs. 2 and 3

included. This can be accomplished by means of a differential in the Q input line, Figure 4. Actually, in most applications this correction is negligible.

The integrator can be used for all angular inputs except in certain singular positions of the mechanism where rotation of the sphere around a contact point can occur. For example, referring to Figure 3, if A equals $\pi/2$ the circle of contact of the cosine output roller will reduce to a point (Cos $\pi/2$ equals 0).

The spherical type integrator can transmit a higher torque than the conventional ball and disk type unit. This results in part from the random manner in which wear is distributed over the spherical surface. On the other hand, the present designs of spherical integrators are not as accurate as the ball and disk integrators because of assembly alignment difficulties and unsymmetrical elastic distortions .

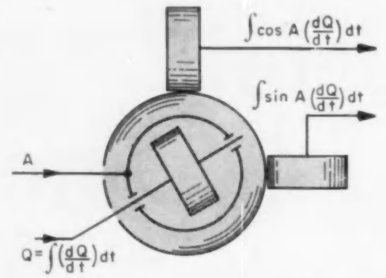
Figures 5 through 9 show ways in which the component integrator can be connected to perform various functions.



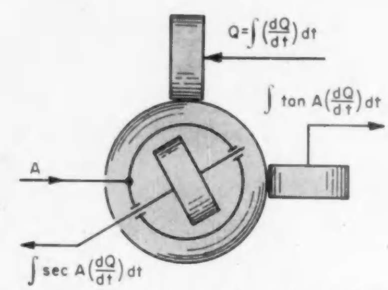
Compensating differential in Q input may be required for high accuracy. Fig. 4

WHAT IT DOES (Next Page)

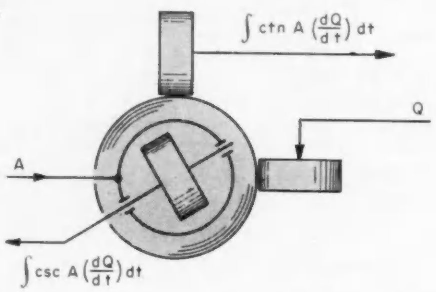
FIVE WAYS TO USE COMPONENT INTEGRATORS



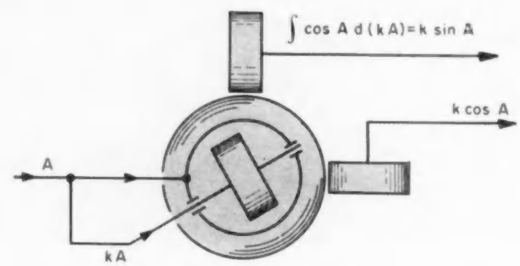
Normal operation of integrator. The output velocity sin A (dQ/dt) is not accurate when A is in vicinity of 0 or π; cos A (dQ/dt) is not accurate in vicinity of A equals plus or minus $\pi/2$. Accuracy is poor when operating within plus or minus 2.5 deg of these critical points. Fig. 5



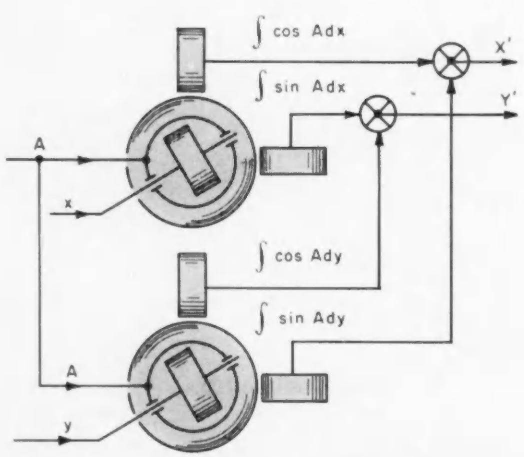
One method of inverse operation. Best when A is in vicinity of 0 or π. Normally only $\int$sec A (dQ/dt) dt output is used since $\int$tan A (dQ/dt)dt output is inaccurate, when A equals 0 or π. Limits of variation of A must be determined by experiment. Usually range of A of plus or minus 70 deg is reasonable. Fig. 6



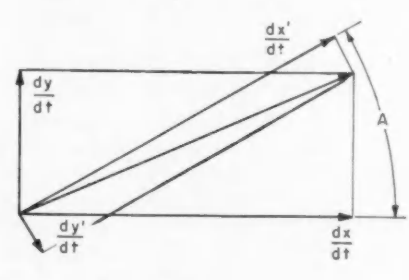
Second method of inverse operation. Best when A is close to plus or minus $\pi/2$. Uusually only $\int$csc A (dQ/dt)dt output is used for A equals $\pi/2$ plus or minus 70 deg, A equals minus $\pi/2$ plus or minus 70 deg. Fig. 7.



Harmonic motion generator. The amplitude of the output sine motion depends on gear ratio between input roller direct drive and input roller angle drive taking into account differential motion effect. Fig. 8



Coordinate transformation. This method of connecting can be applied to the transformation of normal angular velocity components dx/dt and dy/dt to:



$$\frac{dx'}{dt} = \frac{dx}{dt} \cos A + \frac{dy}{dt} \sin A$$

$$\frac{dy'}{dt} = - \frac{dx}{dt} \sin A + \frac{dy}{dt} \cos A$$

$$\text{where } x' = \int \cos A \, dx + \int \sin A \, dy$$
$$y' = - \int \sin A \, dx + \int \cos A \, dy$$

The vectors dx'/dt and dy'/dt are normal angular velocity components along a set of axes inclined at an angle A to the original set of axes. Fig. 9.

EDDY-CURRENT TESTING:

A New Tool Makes Inspection Automatic

RICHARD HOCHSCHILD, U. S. Atomic Energy Commission, Hanford Operations Office

THE PROBLEM: Good inspectors are hard to find, expensive to train. Worse yet, even the best are inconsistent. If a man inspects the same part twice, he may pass it the first time, reject it the next. Production-testing departments are, more than ever, eager to cancel human error in inspection. Eddy-current sensing devices can test many types of metal parts for flaws and other imperfections. They can, for instance, reveal the shape, depth, and location of a tiny crack. And they can fit into systems that automatically reject substandard pieces. For a summary of eddy-current testing's flexibility and versatility, see next page.

Among the many methods of nondestructive testing, eddy-current devices stand almost alone in their selective sensitivity and in their ability to amass test information. In addition, the output information can be compared with a preset electronic memory of desirable and undesirable conditions to decide whether a test piece is good, bad, or mediocre. For automatic inspection, the decision signal can be used to actuate a relay that sends the test piece into accept or reject channels, or it can be recorded in quantitative terms.

Eddy-current testing devices can determine variations in the conductivity, dimension, and shape, and the distance of the test piece from the test coil. The types of testing problems solvable by eddy currents, specifically by the impedance analysis approach to be discussed later, depend on the measurement of one or a combination of these properties.

APPLICATIONS

While in itself of little commercial consequence, conductivity in metals gives an indication of such properties as hardness, purity, alloy composition, porosity, and preferred crystal orientation.

Conductivity is a function of chemical purity and alloy composition in most metals. For example, as little as 0.01 per cent of phosphorus will decrease the conductivity of copper by about 2 per cent, Figure 1. Most other impurities also, as well as variations in alloy composition, affect the conductivity but to a lesser degree.

The presence of porosity changes the apparent conductivity of a piece of metal by crowding eddy currents into a relatively smaller volume. Currents cannot pass across microscopic voids and in being diverted around them raise the current density in the surrounding metal, thereby lowering the effective conductivity.

Most metallic crystals are noncubic and have different conductivities along their different crystal axes. Eddy currents can, therefore, reveal the presence of preferred crystal orientation in metal objects whose crystals are noncubic.

Tests for heat treatment and related conditions, such as hardness and depth of case hardening, have also been devised by making eddy-current equipment sensitive to conductivity variations.

Since the conductivity of a test piece and its dimensions (or position) can be measured individually and simultaneously with suitable equipment, eddy-

How Eddy-Current Testing Offers a SOLUTION.

It can do all this:

- ▶ **Measure the conductivity (purity, porosity) of bars, wires, tubes, without responding to diameter variations.**
- ▶ **Measure the diameter of bars, wires, and tubes regardless of conductivity.**
- ▶ **Measure the conductivity of flat surfaces and small parts with small probe coils independently of the exact position of the coil relative to part or shape of part.**
- ▶ **Measure the thickness of insulating coatings (paint, oil, oxides) on conductors independently of the conductivity of the underlying metal.**
- ▶ **Measure the thickness of sheet metal and foils regardless of conductivity and without direct contact.**
- ▶ **Detect cracks, inclusions, and other flaws in bars, tubes, wires, flat surfaces or other shaped pieces regardless of conductivity, dimension, or probe position.**
- ▶ **Identify both shape and depth of flaws, if other variables stay constant.**
- ▶ **Measure thickness variations in a metallic coating or plating on another metal of different conductivity.**
- ▶ **Sort small parts according to differences in dimensions or conductivity.**

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current devices can be designed for the variety of testing applications listed at end of article.

With coils that encircle the test piece, contact-free determinations of the diameter of bars and other objects can be made to closer than 0.0001 in. On the same basis, tiny probe coils can be used to measure the thickness of oxide, oil, or paint coatings on any metal with still higher sensitivity, since minute variations in the thickness of such insulating coatings slightly vary the distance between the probe and the metal surface. The signal from the pickup coil can be made to respond to such distance variations.

It is possible to make accurate thickness measurements on foils, sheet metal, and metal plates from either side with probes of various sizes and with various exciting frequencies. Thickness determinations may also be made of one metal coated or plated on another metal over a wide range of thicknesses, shapes, and sizes, provided the two metals differ soemwhat in conductivity. Choice of frequency and probe-coil size and shape is important.

Wire can be tested with small encircling coils. Measurements that can be made on wire include accurate determinations of diameter, conductivity, and the presence of flaws. This also applies to tubing, where it is possible to measure wall thickness and the eccentricity of the inner diameter.

Flaws can be detected in all portions of bars, tubes, or wires, but with greatly increasing sensitivity toward the surface. The same applies to discontinuities in arbitrary shapes or test specimens where probe coils may be used. The rapid decrease of sensitivity with depth of inspection is especially pronounced with probes. At and just below the surface, however, sensitivity is high. With suitable equipment, a probe scanning along at 60 ft per min can pick up a discontinuity only a mil wide, a few mils in depth, and a small fraction of an inch long.

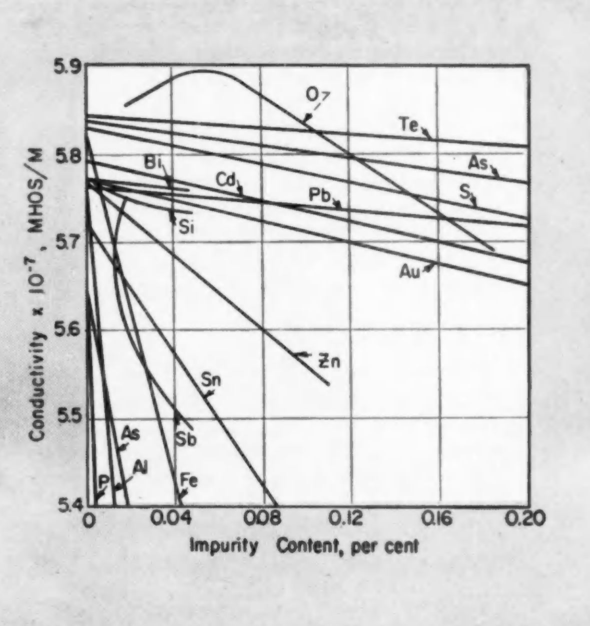
Although eddy current testing can be used on all metals, special precautions must be taken with the ferromagnetic metals (iron, steel, nickel and cobalt). The permeability of all nonferromagnetic metals is so close to that of free space than any variations in permeability can safely be neglected. However, when the ferromagnetic metals are being tested, a strong dc magnetic field must be superimposed on the ac test field to saturate the sample and reduce its effective permeability to that of free space.

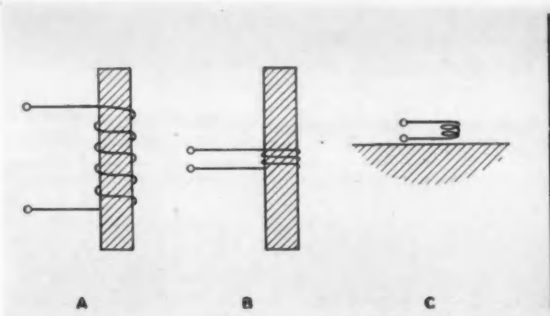
While this article is limited to the use of these devices in automatic inspection systems, they could also be adapted for use in automatic production-control applications. For example, in processes where an insulating coating or plating is applied or sheet metal is produced, eddy-current sensing could be used to monitor the final or intermediate product and control the manufacturing machinery.

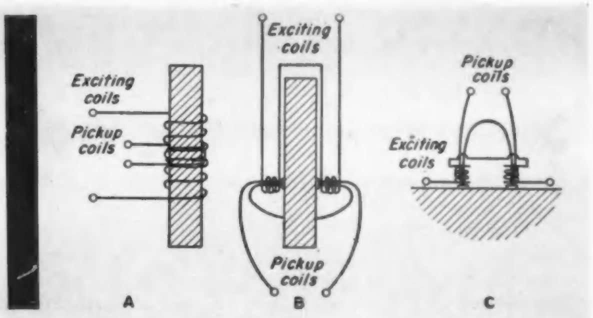
WHAT IS EDDY CURRENT TESTING?

Eddy current testing involves the transmission of energy through a test piece much like the transmission of x-rays, heat, or ultrasonic waves. It is generally less completely understood, because the energy actu-

Impurities influence copper's conductivity. Fig. 1







Possible test coil designs. (A) Wide encircling coil for conductivity. (B) Narrow encircling coil for small flaws. (C) Probe coil for highest sensitivity. Fig. 2

Various difference-coil arrangements. (A) Encircling coils on a bar. (B) Probes on a bar. (C) alternate arrangement of probes on a bar or other surface. Fig. 3

ally undergoes a transformation in the process, from magnetic to electric and back to magnetic.

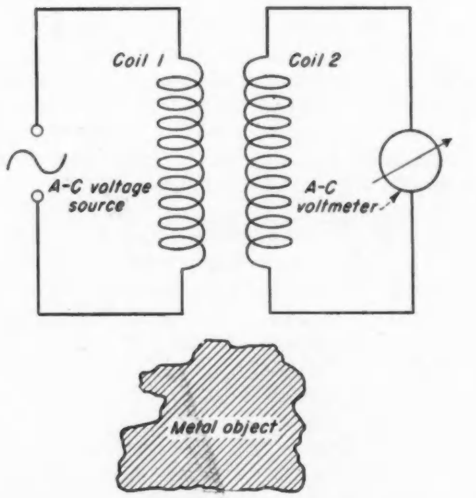
Whenever a piece of metal of any kind is placed in a varying magnetic field, electric currents (known as eddy currents because they follow closed circulatory paths) are set up in the metal. Many of the physical characteristics of the metal such as its size, shape, purity, alloy composition, hardness, or the presence of porosity or flaws help to determine the magnitude, phase, and distribution of these currents. Flaws, for instance, block current paths, diverting the currents around them. The currents and their variations can be measured by suitable detecting equipment because they set up a new magnetic field of their own which is detectable outside of the test piece. This makes it possible to measure several physical characteristics of metal objects by placing the pieces to be tested in an alternating or pulsating magnetic field and making measurements on the resulting field.

The depth of penetration of eddy currents can be controlled by choice of the frequency or wave form of the exciting field. At low enough frequencies, eddy currents can be made to flow in the entire volume of a metal bar, whereas at very much higher frequencies, as illustrated by the "skin effect" familiar in high-frequency electric circuits, they flow only near the surface. Hence the area to be tested can be controlled to some extent.

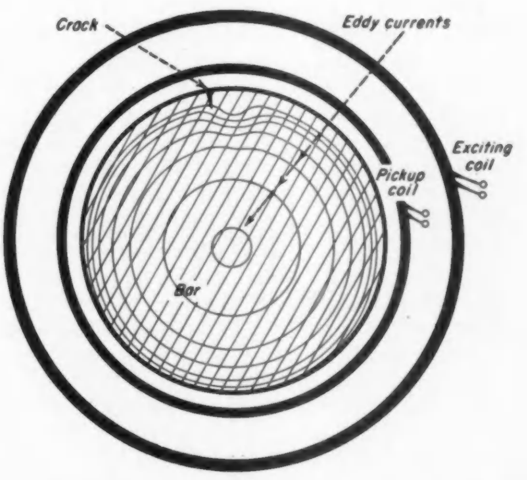
TEST COILS

The exciting magnetic field is produced by an alternating (or in latest schemes by a pulsed) current flowing through a coil. The many different coil designs afford some additional control of the test variables and of the size and extent of the test area.

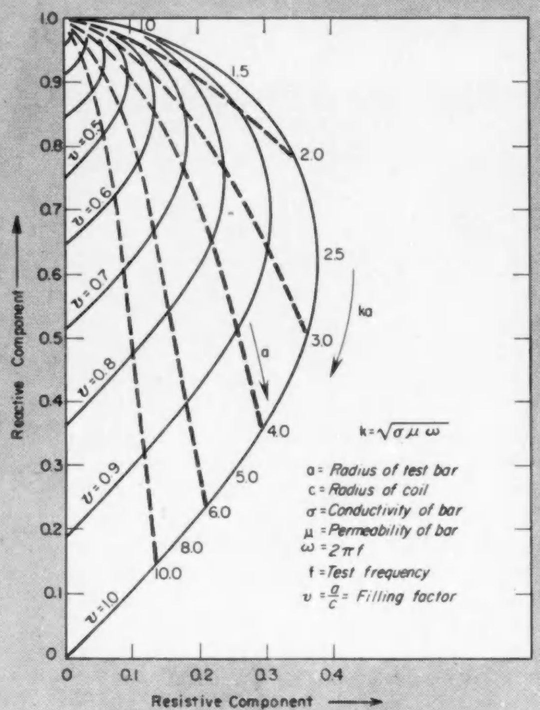
For testing bars, wide coils that encircle the bar, Figure 2(A), are favored for measuring properties that are spread out; for example, over-all conductivity,



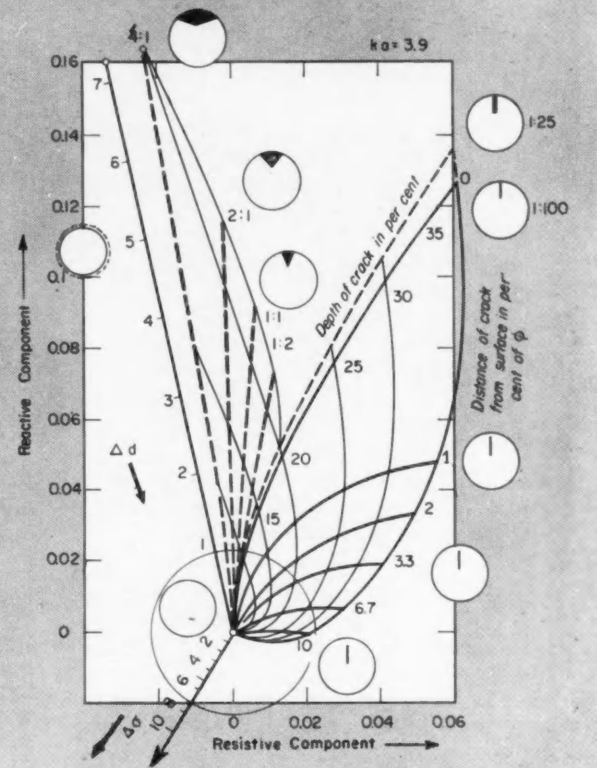
Basic test circuit. Source is sinusoidal, constant frequency. Coils are fixed relative to each other. Fig. 4



Eddy current distribution in the cross-section of a bar surrounded by test coils. Fig. 5



Resistance-reactance plot of coil encircling bar for all values of conductivities and radii. Fig. 6



Effect of various flaws in bars on test-coil resistance and reactance, Fig. 7

hardness, porosity, or purity. On the other hand, narrow coils, Figure 2(B), produce comparatively more sensitive responses to small flaws and local diameter variations since they restrict the test region. Tiny probe coils placed on the test piece from the top, Figure 2(C), can be used when very high sensitivity to small flaws is desired and only the region immediately below the surface is to be tested, or for wall thickness measurements, or whenever it is impossible to surround the test piece with a coil.

The eddy currents set up by the magnetic field from the exciting coil generate a new magnetic field opposing the original field. What is actually measured is the sum of the exciting and the secondary (or eddy current) field. For this purpose a pickup coil, either surrounds or sits on the test piece. Often the coil is a small probe that can be made to scan rapidly over the surface of the piece searching for field irregularities.

The shape and size of the pickup coil need not necessarily conform to that of the exciting coil. A combination of encircling exciting coil and probe pickup (or vice versa) can be used for certain purposes. As another alternative, a single coil sometimes serves as both exciting coil and pickup coil.

It is often advantageous to split the pickup into two coils, Figure 3(A), or probes, Figures 3(B) and (C), and connect these in series opposing. The coils can remain close together on the test piece so long as they do not interfere. If necessary, they can be shielded from one another. Their combined output is now equal to the small difference of the signals rather than the large signal produced when they were a single coil. This difference may be amplified. Because the coils are fairly close together, the two metal areas they inspect are likely to have quite similar properties, unless some sudden discontinuity exists between them. A small flaw is such a sudden discontinuity and will produce a large difference signal.

As an illustration of the importance of their careful design, the coils and their arrangement can be likened to lenses in an optical system. Depending on how the lenses are shaped and positioned relative to one another, the system can be either a telescope, a microscope, a spectroscope, or a camera, each with its own particular applications. The shape of the test coils is, therefore, a fundamental consideration and will depend on the nature of the test.

WHAT IS MEASURED?

A simple eddy current test arrangement is shown in Figure 4. The alternating voltage in Coil 1 sets up an alternating magnetic field around the coil. If Coil 2 and the test piece are close enough to Coil 1 to intersect some of the flux lines of the magnetic field, currents will be induced in them.

If the position of the sample changes but everything else about it remains the same, the voltage reading across Coil 2 will drop as the sample is brought closer to the coils. The eddy currents in the sample produce an opposing magnetic field that weakens the original field of Coil 1. Coil 2 responds

to the resultant field, which decreases in strength as the sample cuts more and more line of magnetic flux. The same effect is observed whenever the sample grows in size or increases in conductivity or does both.

The exact dependence of the voltage reading across Coil 2 on any of these effects is not linear, nor is it particularly simple. The situation is complicated by the fact that a voltage has both a resistive and a reactive component, neither of which necessarily varies linearly with any of the effects. These two components are useful, however, for by measuring them separately it is possible to determine simultaneously, two independent pieces of test data, such as dimensions and conductivity.

The object is to establish quantitatively the relation between

- the resistance and reactance of a test coil and
- the conductivity and the dimension or position of a test piece.

Curves are available by which resistive and reactive changes in the test coil can be translated directly into changes in conductivity and dimensions or both (or conductivity and position or both).

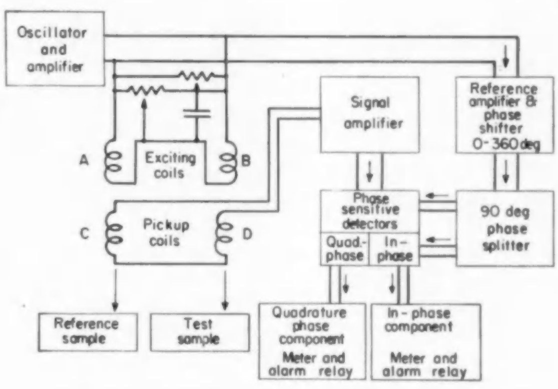
IMPEDANCE ANALYSIS

While most types of nondestructive tests present only one piece of data, such as the intensity of transmitted radiation or a pattern in powder, eddy currents can present two. These are the resistance, R, and the reactance, X, of the pick-up coil. This leads to a two-dimensional rather than a one-dimensional analysis. A direct functional relationship exists between R and X, on the one hand, and the amplitude and phase of the measured voltage, on the other. The measured voltage depends on the magnetic field, the field depends on the eddy currents, and the currents in turn vary with the dimensions and conductivity of the test piece, and the shape, size, and position of flaws within it. For example, once the functional relationships have been established, a response to a narrow but deep crack can be differentiated from a response to a shallow but wide crack, or from a purity variation, or a dimensional variation.

Since the conductivity and diameter variations take different directions, electronic circuitry can be designed to be insensitive to variations in any particular direction on the graph and to measure only the components of variations in a direction that is perpendicular to the direction of insensitivity. Thus equipment can be designed that will measure conductivity variations independently of diameter variations.

The effect of various types of flaws in a bar on the reactance and resistance of the test coil is shown in Figure 7, which is actually an enlarged view of the section of the graph in Figure 6 around the point ka equals 3.9, ν equals 0.9. Assume that a sound specimen falls at the point (0,0) on the graph in Figure 7. When a narrow crack that starts at the surface appears in the specimen, there is a change in the reactance and the resistance of the test coil along the curve number 15, 20, 25, 30, 35. The numbers express the depth of the crack in per cent of the diameter of the bar. If on the other hand the crack starts below the surface, a different change takes place as illustrated by the colored curves that end in the numbers 1, 2, 3.3, 6.7, and 10 on the graph. These numbers refer to the distance between the top of the subsurface crack and the surface of the bar, again in per cent of the diameter. Finally if the crack is not narrow but varies in width, the changes illustrated on the left side of the graph takes place (colored dotted), the ratios referring to the width-to-depth ratio of the crack. The straight line labeled Δd illustrates a pure diameter variation and the line $\Delta \sigma$ a pure conductivity variation. The impedance approach, therefore, affords many kinds of analyses not possible with other equipment.

Thus on an impedance graph the direction of the pickup-coil impedance change identifies the physical origin of the change whereas the distance of the change represents its magnitude.

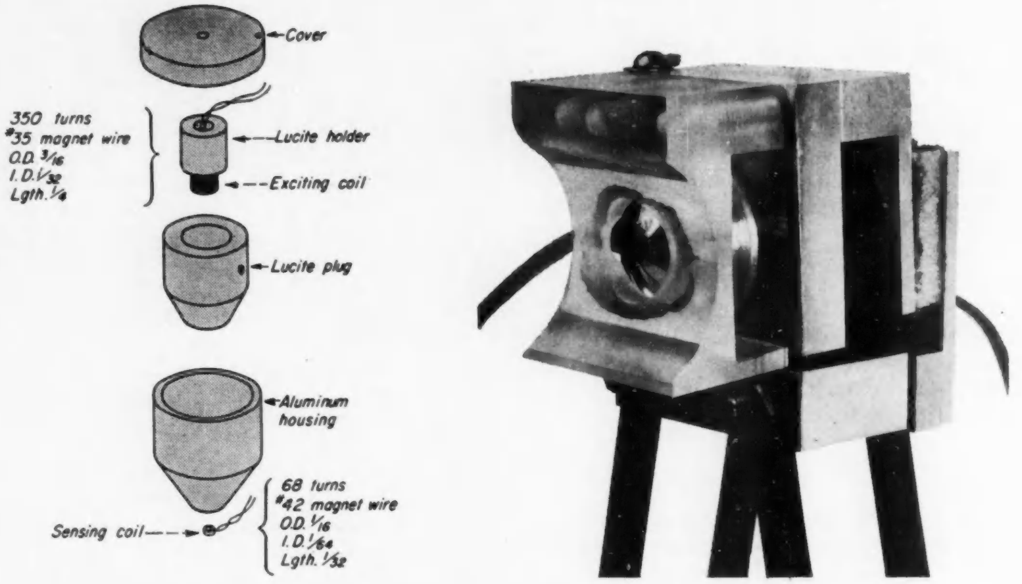


Block diagram of typical phase-sensitive eddy current instrument now available in the U. S. Fig. 8

EDDY CURRENT TEST EQUIPMENT

The block diagram shown in Figure 8 is typical of a new group of eddy current instruments developed by F. Förster and associates in Germany and available in the U. S. under the name Magnatest series from the Magnaflux Corp.

An oscillator-amplifier supplies a constant frequency current to the exciting coils A and B of the test coil system. Physically the system could be like any of those shown in Figure 2 or it could consist of a single exciting-coil and pickup-coil test system in series with an identical system applied to a reference sample as indicated in Figure 8. The net output signal of pickup coils C and D is amplified and then fed into a phase-amplitude-sensitive detector. A reference channel, energized directly from the oscillator, gives



Exploded view and photograph of special test probe. Lucite mask positions it accurately on the bar, acts as a slipper bearing, and protects the exposed pick-up coil. Fig. 9

two reference voltages separate in phase by just 90 deg. but adjustable in phase relative to oscillator output. Two ring-modulator phase-sensitive detectors, designated as quadrature-phase and in-phase detectors, measure the amplitude and phase relations of the net pickup-coil output voltage. Meters, alarms, or automatic rejection relays can be attached to the quadrature-phase and in-phase detectors.

The output of the in-phase detector indicates the amplitude of the component of the signal voltage which is in phase with respect to whatever reference voltage is supplied by the reference amplifier and phase shifter. The output of the quadrature-phase detector indicates the amplitude of the component of the signal voltage which is 90 deg. out of phase with the reference voltage. When the phase shifter turns through 360 deg., the output of either detector will, at some phase angle, be zero for a particular signal voltage. Thus if the phase shifter is rotated until the quadrature-phase detector reads zero, then output of the in-phase detector will be proportional to signal amplitude and position of the shifter will establish relative phase of the signal. Hence both amplitude and phase can be read.

Signal amplitude and phase are the two independent pieces of test data required, for they have a useful meaning on an impedance graph. On the graph, the amplitude of the signal corresponds to the linear distance of the change, while phase identifies the direction of the change. Suitable choice of the reference phase will make the in-phase meter read only those signals that have components in a certain direction on the graph. This means that it is possible to eliminate responses in any particular direction; for example, conductivity responses or diameter responses.

In work supported by the Atomic Energy Commission at the General Electric Company's plant at Hanford, Wash., the theory of the Förster instruments has been carried further and new contributions have been made. One of these is the design of several highly sensitive and specialized test probes. This equipment, developed by E. C. Wood, H. L. Libby, and associates, includes automatic conveyors and divorces the test completely from human interpretation and judgment. Nonstandard pieces are identified by the flash of a red light, or are automatically rejected by a relay-activated switch.

Both an exploded view and a photograph of one of these probes used for testing bars is shown in Figure 9. In principle, this probe is similar to the system depicted schematically in Figure 3(B). High resolution is insured, in part, by keeping the pickup coil as small as possible. The probe is spring mounted and in normal use rides on the test bar as the bar simultaneously rotates and traverses beneath it at high scanning speeds (several feet of bar a minute). Phase-sensitive detection electronics eliminate the effects of vibration between probe and bar as the bar rotates during test.

Results with this equipment indicate that the new methods are very promising in a wide range of applications and that they offer a combination of rapid, reliable, and automatic inspection.

Acknowledgement: The author would like to give credit to F. Förster for developing much of the material that was presented in this article.

HOW EDDY CURRENT TESTING COMPARES WITH OTHER NONDESTRUCTIVE INSPECTION METHODS

Test Method	*Inspection Applications*	*Principles Of Operation*	*Remarks*
Visual Inspection	Visible surface flaws, conditions, and dimensions, in any material.	Inspection by eye without auxiliary aids.	Limited to what eye can see and by inspector's ability to interpret and react to what he sees in a given time.
Dye Penetrant	Detection of surface flaws in many materials.	Part is dipped into an oil-base penetrant, washed, developed, and visually inspected. Dye may be fluorescent under ultraviolet light. Defects stand out clearly.	An aid to visual detection, applying only to flaws that reach the surface. Requires pre-inspection processing and is not adaptable to automatic handling.
Magnetic Field	Ferromagnetic parts only, for surface and sub-surface flaws and such other conditions as hardness, alloy composition, purity, and internal stresses affecting magnetic properties.	Magnetic properties, such as permeability, coercive force, residual flux, and leakage flux (produced by flaws) are measured by applying a magnetic field in any of a variety of ways. Detection means include pickup coils and magnetic powder particles.	Particle methods aid the eye but retain basic limitations of visual inspection. Electronic detection methods can be fully automatic and usually are faster and more sensitive.
Eddy Currents	**Detection of flaws and measurement of dimensions and other conditions including purity, alloy composition, hardness, and heat treatment in metal parts.**	**Electric (eddy) currents are excited in the test part by an ac magnetic field. A pickup coil can be used to measure the amplitude, phase, and distribution of these currents as they are diverted by flaws or otherwise changed by variations in the physical condition of the test piece.**	**Method is fast, simple in operation, requires no auxiliary processing, and is particularly suited to automatic inspection and rejection. Although very sensitive to certain surface and sub-surface flaws and conditions, it loses sensitivity with depth of penetration.**
Electric Field	Variations in the dimensions of metallic parts, dielectric properties, or composition of nonconducting objects and the presence of flaws.	An electric field is established within the part or between the part and its surroundings. Electric field strength, leakage flux, or the breakdown of the electrical field can be measured.	Adaptable to automatic handling in certain applications.
Radiography	Surface and internal flaws, conditions, and dimensions in metals and nonmetals whenever these effect the transmission of a penetrating radiation.	Test object is exposed to beams of penetrating radiations (x-rays, gamma rays, neutrons beams) whose transmitted intensity is modified, for example, by defects in the object. Detection can be by photographic film, fluorescent screens, geiger counters or other radiation detectors.	In most applications, radiography requires time and some skill on the part of the inspector. It is therefore not generally adaptable to rapid automatic testing. However, some electronic and automatic inspection means exist and others are being developed.
Ultrasonics	Detection of surface and internal flaws, determination of thicknesses, and measurements of metallic grain size.	Ultra-high frequency vibrations are used to located flaws because most materials reflect ultrasound when there is a discontinuity, break, or inclusion in the material. Grain size, orientation, and other conditions can also affect ultrasonic properties. Electronic detection circuits display the reflected or transmitted signal on a cathode ray screen.	Method is fast and requires no processing. Sensitivity is usually not seriously affected by depth of penetration, and defects can be detected in some parts that cannot be penetrated by radiography. Because interpretation is necessary in many applications, the method is not commonly adapted to automatic testing.

For a more detailed evaluation of nondestructive tests refer to Special Technical Publication No. 112, "A Basic Guide for Management's Choice of Non-Destructive Tests" by R. C. McMaster and S. A. Wenk published as part of the Symposium on the Role of Non-Destructive Testing in the Economics of Production by the American Society for Testing Materials, 1951.

CONTROL IN EVOLUTION:

Analysis Moves from Lab to Line

Out in the plant, continuous analyzers are opening the way to instantaneous control of stream composition. They suggest we are but a black box away from truly continuous processing.

PAUL A. WILKS, Jr., The Perkin-Elmer Corp.

Lay prophets of the manless factory pridefully point to today's highly instrumentized chemical processing plant. Huge quantities of materials flow through its complex network of pipes into fractionation columns, purification towers, and reactors with very little human attention. Enormous amounts of finished product are pumped into pipe lines and storage tanks without ever having been seen by human eyes.

That such a complicated system will function at all is due largely to the myriad dependable control instruments present in any processing plant. They control the flow of raw material and product through the maze of pipes. They provide exactly the proper pressure and temperature to produce the highest product yield. In short, these instruments make possible this closest approach yet to the completely automatic factory.

But even when every instrument indicator in the great control room of a chemical-processing plant is reading correctly, the product yield in terms of quality or quantity may be completely awry. Suppose the composition of a raw material changes, or a scrubbing tower slips slightly in efficiency, or a catalyst becomes contaminated. These and many similar disturbances can take place in the streams without a sign from the process instrumentation.

For as things stand today, virtually every instrument is in reality controlling a secondary variable. Few or none indicate anything about the product and its composition as it moves down stream.

Because product is paramount, every processing plant has an external sensory apparatus called the "control laboratory". Here the raw materials and intermediates from the streams—as well as finished product—go for periodic evaluation. Here the subtle deviations are spotted and analyzed. And from here go communications to process areas prescribing reshuffling of control instrument settings.

Thus, true control in processing, as it exists today, begins in the analytical laboratory. Without analysis, there can be no guarantee of efficient, profitable production.

Diagnostic Delay

Control laboratories are vital, reassuring, but painfully slow in comparison to modern processes. Collecting and moving samples to the laboratory takes time. Manipulating and interpreting analytical instruments consumes more. And relaying findings back to the plant control room extends this routine into a tedious ritual.

But a highly geared industrial process won't wait. Fifteen minutes lag in analysis can often spell carloads of spoiled product.

Control engineers have tried to do something about this diagnostic delay. An obvious first step was to mechanize and speed up the laboratory instruments. Instrument companies responded by applying new analytical principles to produce faster

and more accurate measuring and control equipment.

Even the interpetation of laboratory data was mechanized. For example, an infra-red spectrometer was recently set up to punch out quantitative analysis of a ten-component sample using an electronic readout and computer to solve the simultaneous equations (see CONTROL ENGINEERING, Sept. 1954, page 87).

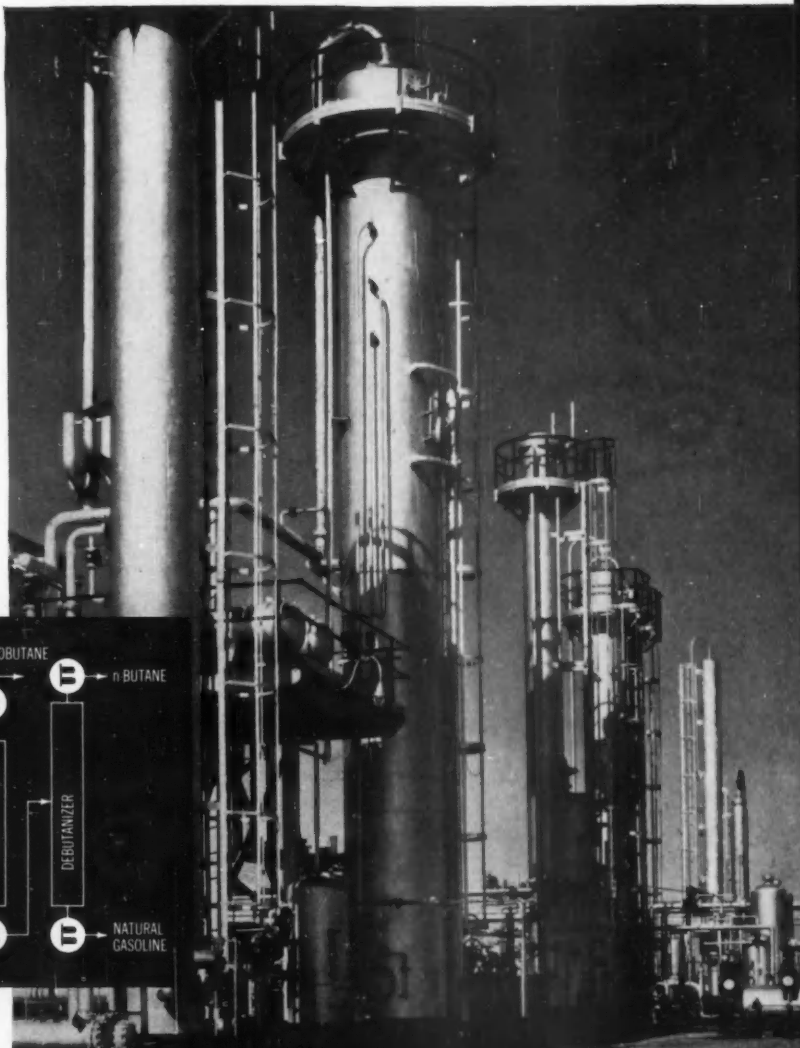
But even with mechanized bench analysis, the lag is formidable, particularly in sampling routine. The obvious solution would be to "move the laboratory to the problem", i.e., to tie the infra-red spectrometer directly into the process stream, where it can produce continuous and instanteous data.

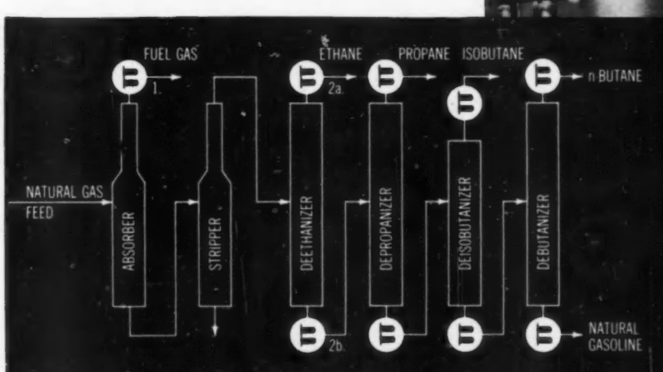
Instruments capable of providing "on-stream analytical control" are just now beginning to appear. They can record stream compositions directly, thus making available the prime data that is necessary for true automatic control. These new analytical controllers do not in any sense replace the existing environmental controllers, rather they are a means for automatically adjusting the latter instruments to meet changing stream conditions. In a sense, they "close the loop" between the product and the environment in which it is produced. Today some of the new breed—on-stream analyzers—are being watchfully installed by industry.

The on-stream analyzer is very much a direct

WILL THIS BE THE FIRST COMPUTER-CONTROLLED PLANT?

Gas-recycling plants are as near to the automatic process as any today. But on-stream infra-red analyzers, diagrammed below, have already set new recovery and separation standards in at least one of these plants. Author Wilks argues that the stream analyzers added to this type of operation can make it the first computer-controlled plant.





descendent of the classic laboratory tools. Hence, before detailing operation and application of the new analyzers, let us consider their progenitors.

Single-valued vs Multi-valued

Basically, two classes of analysis instrumentation exist in the lab: single-valued and multi-valued. Single-valued types have long been used and are universally familiar. Some examples are the pH meter, refractometer, density control. All these measure a single characteristic of material.

Multi-valued instruments have appeared only in recent years and are generally more complex. Three important types are the infra-red, ultra-violet, and mass spectrometers. These measure a multi-valued physical property of a material—its absorption or mass spectrum— and thereby tab its composition.

A good analogy between the two approaches to product analysis lies in the Rogues Gallery. A fingerprint more positively identifies a criminal than the most complete physical description. The spectrometers create a product fingerprint. A single spectrum, made in a few minutes, will positively identify a product that cannot be described by any one of such physical measurements as refractive index, boiling point, pH, and density.

The new spectrometers have been developed commercially during the last fifteen years. They are not cheap—costing $5,000 to $40,000, as compared with $1,000 or less for most single-valued instruments. They are complex in design but usually can be run easily once a routine is established.

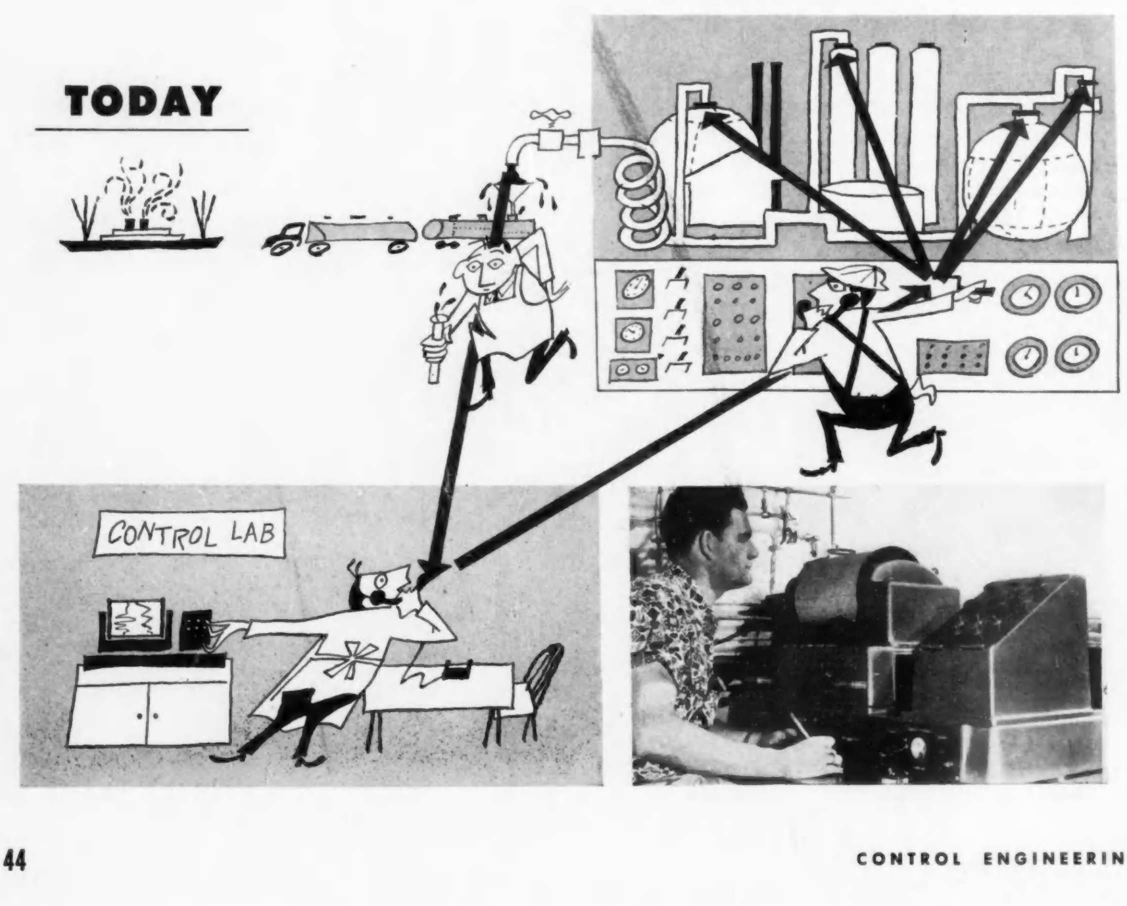
The economic value of this new class of instruments shows up in time savings and accuracy. They give the control chemist in minutes what he would get only after hours of conventional analysis such as fractional distillation and point determinations. And their accuracy often makes possible simplified processing, which saves money.

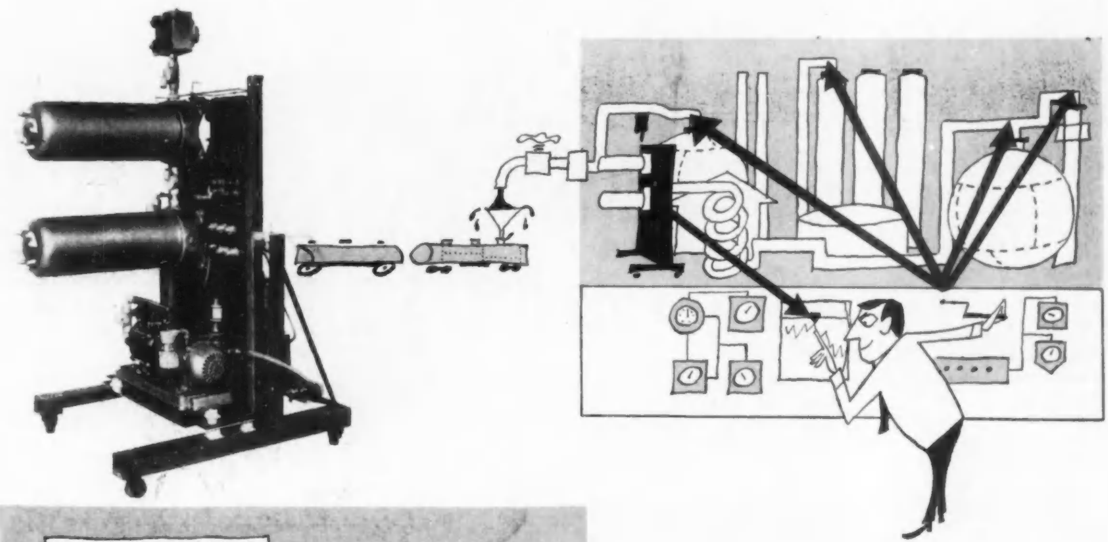
A case in point is a large gas-cycling plant in Texas. One of its principal products is 95 per cent isobutane. By conventional methods, isobutane can be determined with plus or minus 2 per cent error. As a result, this plant was forced to produce material that analyzed 97 per cent pure in order to be sure that it met specifications.

Routine infra-red analysis gave an error of plus or minus 0.2 per cent. This made it safe to aim at 95.5 per cent purity. Since the last stages are most difficult and costly in purifying processes, this accurate analytical check meant big savings in manufacturing costs.

Infra-red analysis also saved time. The former fractional distillation and weathering test took six hours. This was cut to one-half hour.

Despite, or perhaps because of, the gains in time





TOMORROW

and accuracy in this and in similar installations, some users are as dissatisfied as ever. Someone still has to collect samples and bring them to the laboratory. Often, someone has to man the instrument during swing and night shifts. And even though the new analysis takes only a few minutes, anything radically wrong with the process is always spotted just a bit too late. Hence the need for the on-stream analyzer.

Theoretically, any analysis which can be performed in the lab should be possible on a continuous basis in the stream. But, in developing on-stream analyzers both makers and pioneering user companies had to take into account the following requirements:

- ►Continuous Sampling—getting a representative sample to the unit is a problem in most processes. It must be dirt-free and homogeneous.
- ►Ruggedness—the unit should be able to withstand the hazards of jarring, vibration and attack by monkey-wrench mechanics.
- ►Serviceability—down-time on an instrument of this type must be kept to absolute minimum. Its components should be long lived and easily replaced.
- ►Hazardous Location—there should be no chance of the instrument setting off an explosion.
- ►Ambient Extremes—plant temperatures may vary over 100 deg F. The instrument must be automatically compensated for thermal swings.

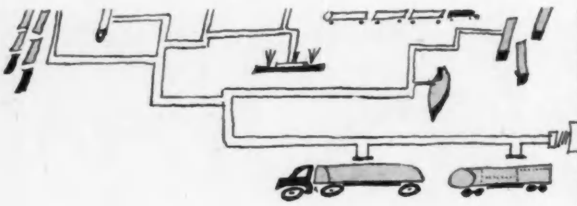
New techniques developed by industrial instrument designers meet most of these requirements. As a result, dependable on-stream instruments based on infra-red, ultra-violet, and mass spectrographic principles are now available. Perkin-Elmer's Trinon and Bichromator analyzers are examples, both being designed to monitor a particular component in a process stream.

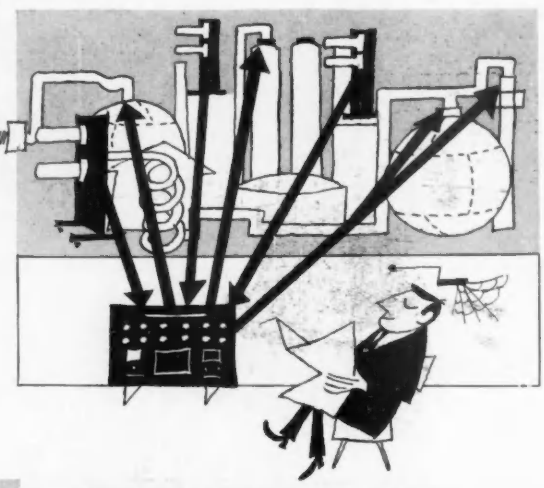
Functional Use

Functionally, the Bichromater analyzer is a much-simplified version of a laboratory spectrometer. It is a dispersion-type instrument, which means that it can be made to select specific narrow bands of infra-red radiation.

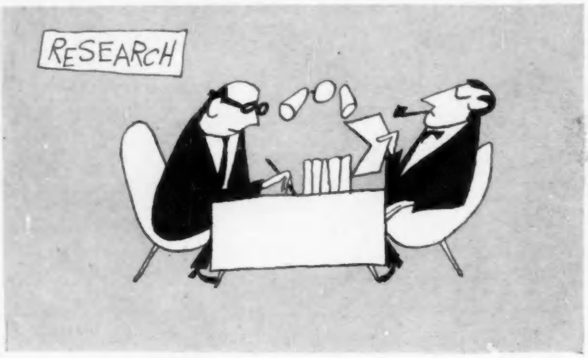
Before installation the Bichromator is preset to two selected wave-lengths—one that is absorbed by the component of interest, and one that is not. It records the ratio of the energies of these two wave-lengths. This value is proportional to the amount of component present and is the data recorded in the central control room. In operation, liquids or gases are bled from the stream through the unit.

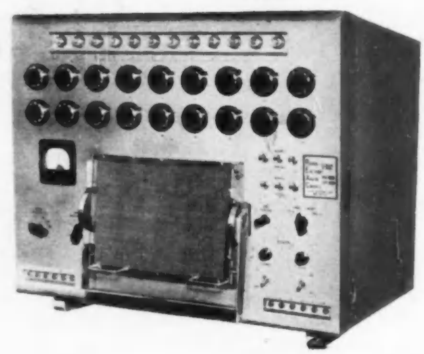
AND AFTER TOMORROW? ►





NEXT WEEK





Though intended primarily for gas analysis, the Tri-non Analyzer may also be used for liquid stream analysis. It differs from the Bichromater in that it makes use of the entire infra-red-spectrum wavelengths absorbed by components other than the one of interest. The latter is compensated out by means of the Tri-non's unique triple-beam optical system. Hence, it is a nondispersion instrument. Like the Bichromator, the Tri-non analyzer produces a signal proportional to the component of interest.

The most obvious application of continuous analyzers is to monitor the finished product. But in a complicated chemical process where many variables may affect the process, end point analysis alone does not provide enough information for control. Hence analyzers are usually installed at several critical points in the process.

Closing the Loop

Thus, the tools for true "control by analysis" are here. But there are still many problems to be solved before this outer, or "master," loop can be closed around the process. Not all analyses can as yet be made on a continuous basis. In petroleum refining, for instance, final products are mixtures of a great many components. Measuring just one of them is not enough for continuous control.

Continuous analyzers will continue to be primarily indicators until more is understood about the dynamics of most processes. To have the on-stream analyzers automatically controlling stream variables, researchers must take the following steps:

1–First determine the critical stream components.

2–Next isolate the important variables influencing these components.

3–Develop a mathematical corellation between stream composition and stream environment.

4–Then design a computer to fit between analyzer and environmental controls.

The complexities in solving the dynamic equation for each process are enormous. But a growing number of control engineers are at work in dynamic analysis. Lefkowitz at Case Institute, for example, is currently establishing formulas for the behavior of an oil-hydrogenation process, which should eventually place it under complete analytical control.

The writer believes, however, that the first truly automatic process will be a relatively uncomplicated operation, such as a gas-recycling plant. This sort of process is highly automatic already and simple in its chemical dynamics. Five years should see a plant of this type running without any human guidance.

Have you thought of

Characterizing Valves Through Feedback?

HENRY M. PAYNTER, Massachusetts Institute of Technology and Pi[2] Engineering Co., Inc.

Designers tax their talents to get desirable valve characteristics for the regulation of pressure and flow. The effort manifests itself through:

▶ Careful, or elaborate, design of valve geometry.

▶ The use of cams to relate valve stem position with actuator stroke.

Both approaches suffer practical drawbacks, not the least of which is the expense involved. Considerable disappointment often follows the first approach, when the valve performs only passably in service. And development of proper cam shape necessitates cut-and-try in situ. The success of all such methods requires a nearly certain knowledge of physical behavior—pages and pages of valve characteristics.

Feedback control methods, on the other hand, demand a bare minimum of advance knowledge of system performance prior to installation. Only the ranges of significant variables and the qualitative nature of their interrelationships need be known. Moreover, the feedback approach relies on only standard components.

VALVES AND ACTUATORS IN REVIEW

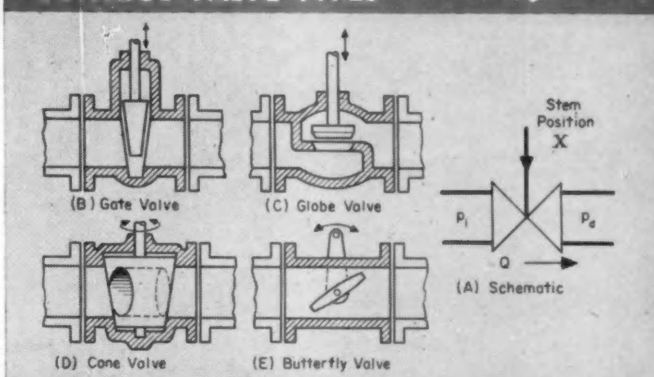
Figure 1 shows a schematic diagram of a control valve along with some of the standard valve types. There are characteristic relationships between inlet pressure p_i, discharge pressure p_d, valve opening A, and flow Q (in units of either volume or weight). Valve opening A relates to stem position X in a way that depends on valve geometry.

A general valve-actuator schematic and three types of valve actuators are shown in Figure 2. Stem position X is proportional to air pressure p in the pneumatic actuator. Hydraulic and electric actuators are time-integrating or accumulative. As long as hydraulic fluid or field excitation is applied, the valve moves to one extreme position or the other.

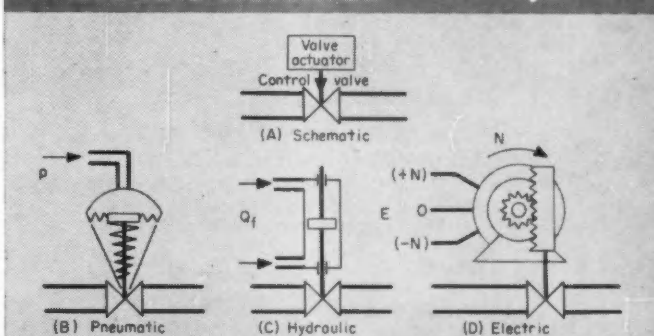
FEEDBACK

The valve actuator is ordinarily under the command of a feedback position control. It permits

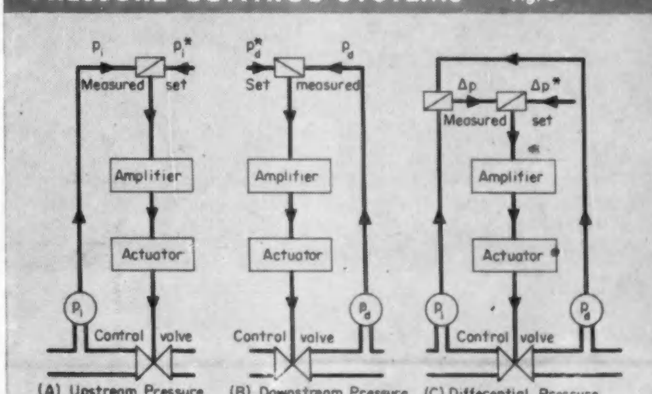
CONTROL VALVE TYPES Fig. 1

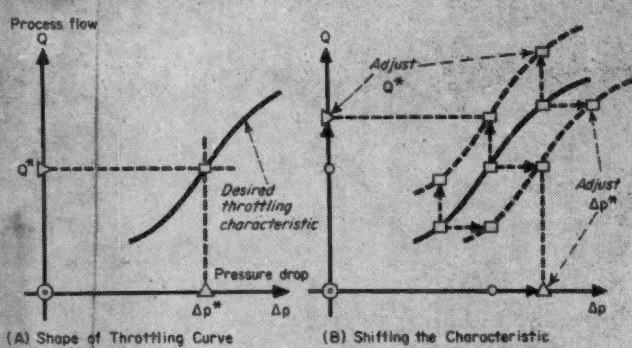


VALVE AND ACTUATOR Fig. 2



PRESSURE CONTROL SYSTEMS Fig. 3





Combined pressure-flow control produces desired valve characteristic. Fig. 4

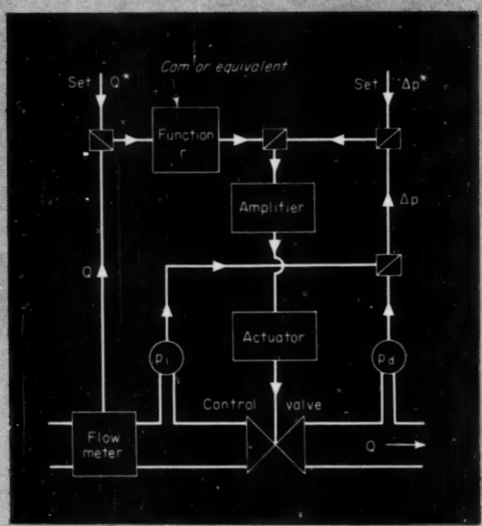
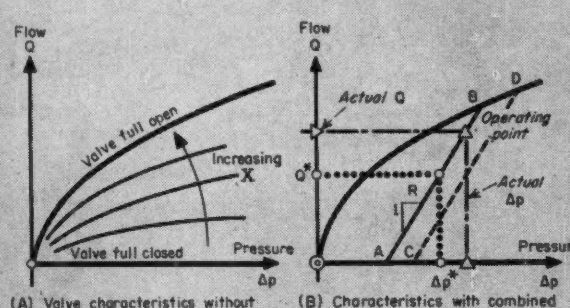


Diagram of control system which maintains programmed relationship (r) between pressure and flow. Fig. 5



The control system can make the pressure-flow relationship linear. Fig. 6

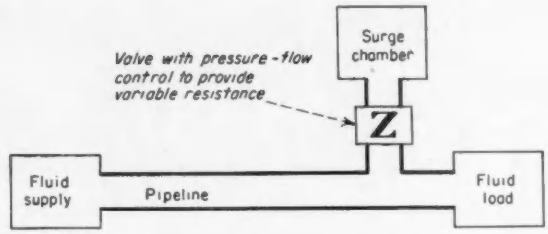


Figure 7 Variable Damping for Surge Control

a variety of power amplifier and actuator components with minimum effect on system response.

The key ideas for a more general use of feedback arise from considering the use of a valve to control pressure or flow. Figure 3 illustrates schematically three types of pressure control:

inlet pressure,
discharge pressure, and
pressure drop.

We are not interested in the position the valve assumes. The position is forced on the valve by the indirect feedback of measured pressure.

As long as the valve takes up a definite position to maintain the desired pressure or pressure drop, the system is stable. Otherwise, the system is unstable.

Feedback systems are commonly used for flow and pressure control. Available equipment is directly applicable to the characterizing methods.

SPECIFIC USES OF FEEDBACK

Consider the case in which neither fixed flow control nor fixed pressure control is wanted. What is wanted instead is a programmed relationship between flow and pressure. As a special case, consider a situation in which the process flow, Q, must be related in a curvilinear fashion to the pressure drop across the valve, $\Delta p = p_1 - p_d$. The curve in Figure 4 shows the desired relationship. The feedback scheme shown in Figure 5 secures the relation. There is provision to adjust either Q^* or Δp^*, as indicated in Figure 4(B). Q^* shifts the characteristic vertically and Δp^* shifts it horizontally. The cam fixes the relationship, r, between $(Q^* - Q)$ and $(\Delta p^* - \Delta p)$.

As a second special case consider the task of "linearizing" a valve whose original characteristics are shown in Figure 6 (A). In this instance the function r becomes a constant slope or "resistance," R, provided by a linear cam or linkage. Slope and origin are adjustable, as indicated in Figure 6(B). The heavy line A-B shows a particular operating characteristic. Another characteristic, shown by the line C-D is obtained merely by decreasing Q^* or increasing Δp^*. Precise operation along the characteristic curve occurs only at equilibrium, or steady state. If the overall amplifier-actuator-valve gain is sufficiently high, the characteristic is traversed at significant speeds.

VARIABLE DYNAMICS

An extremely useful system evolves when the cam is replaced by a mechanical structure or electrical network containing time-varying elements. Dynamic resistance is extremely effective in the fluid surge chamber shown schematically in Figure 8. The variable damping obtained reduces pressure fluctuations far more than fixed damping.

The methods discussed generalize in many other ways. Consider this brief delineation of certain phases of the feedback characterization of control valves as a sampling, far from exhaustive, of latent possibilities in this direction.

Solving Cubics This Way Is Easy

WILLIAM H. GABLE, Aircraft Armaments Inc.

An engineer who analyzes control systems often has to solve polynomial equations. He particularly wants to find negative real roots, for if the characteristic equation of a system has any positive real root, the system will be unstable.

Here is the way to find the negative real roots of an equation without bothersome algebra or tedious trial and error. Take a cubic in its most general form:

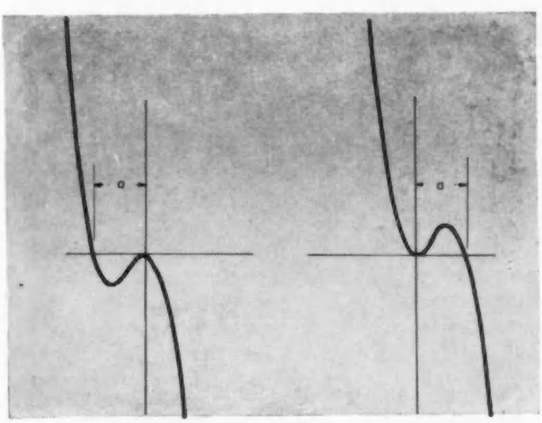
$$x^3 + ax^2 + bx + c = 0 \qquad \text{Eq. 1}$$

a, b, c being real numbers, positive or negative.

Transpose the first two terms:

$$bx + c = -(x^3 + ax^2) \qquad \text{Eq. 2}$$

Now set the right-hand side of the new equation equal to y and plot it. If the coefficient a is positive, the curve will look like the sketch at the left. If a is negative, it will look like the sketch at the right.



One curve is a mirror image of the other, reflected across the point *(0, 0)*.

The left-hand side of the equation is a straight line that intersects the y-axis at *(0, c)* and has a slope equal to *b*. That is, the tangent of the angle the line makes with the x-axis equals *b*. Wherever the curve and straight line intersect, the x-value of the point will be a real root of Equation 1.

Anyone who has to solve cubics frequently need not go through the whole rigamarole repeatedly. He can plot the curves, once and for all, for many values of a. If he is interested in only negative roots, he can skip all values to the right of the y-axis. But for the sake of clarity, he ought to scale the y-axis in units of ten, and he ought to draw one plot for negative a's and another for positive a's (see Figure 3). How big he makes the graph and how many curves he draws depend entirely on what accuracy he wants. Like a slide rule, the bigger such a nomograph is, the more accurately it can be read.

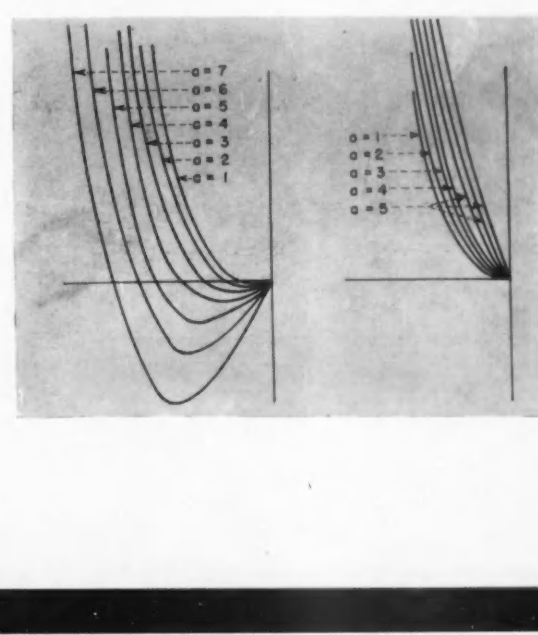
From the families of curves, he can almost instantly find a negative real root with a ruler and protractor. He simply lays the ruler on the paper so that it intersects the y-axis at *(0, c)* and then swivels it until it meets the x-axis at the angle whose tangent equals *b*. Then he reads off the value of x where the ruler crosses the proper curve. This value is a root.

When it comes to using the nomograph, here are some further tips:

► If a, *b*, and c are all positive numbers, the equation may have three negative real roots, but the ruler will show only one or two of them. When you know one root, however, you can factor out that root and break the cubic down into a quadratic.

► If the ruler fails to cross the curve (which has no bends beyond those shown in Figure 3), this means that the equation has no negative real roots.

► If a and c are negative and *b* is positive, don't bother about negative real roots. There won't be any.

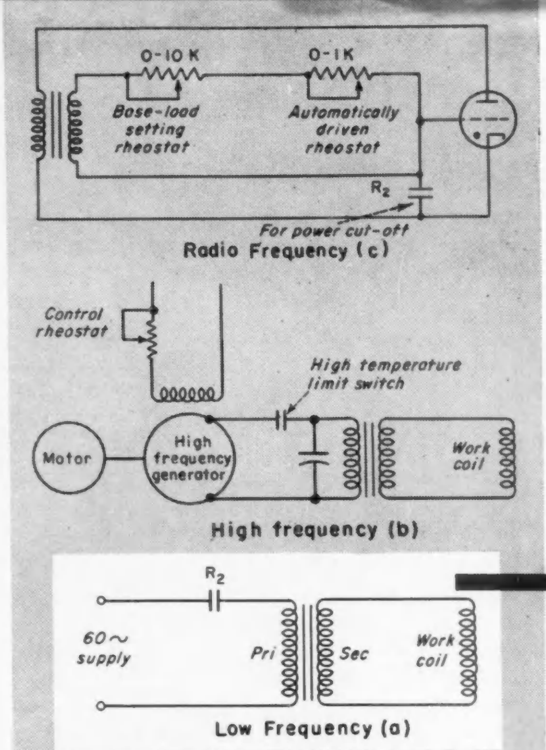


GET UP TO DATE ON

Induction Heating Control

JOHN V. METZGER

Brown Instruments Division
Minneapolis-Honeywell Regulator Co.



REGULATING CIRCUITS FIG. 2

Modern Processing of metals by induction heating requires accurate and reliable control. The results are:

- **Consistently higher product quality through more uniform regulation of heat, and**
- **Safe-guarding of equipment and work, thus**
- **Reduced over-all production costs.**

Induction heating transforms electrical energy into heat in a conducting material which does not come in contact with the power source. Regulation of the electrical energy controls the heat generated.

The workpiece (or charge) is placed in the magnetic field produced by a flow of current through a number of turns of wire (the work coil). The eddy currents induced in the workpiece are the primary source of heat. Hysteresis intensifies the effect in magnetic materials, making them heat faster than non-magnetic materials.

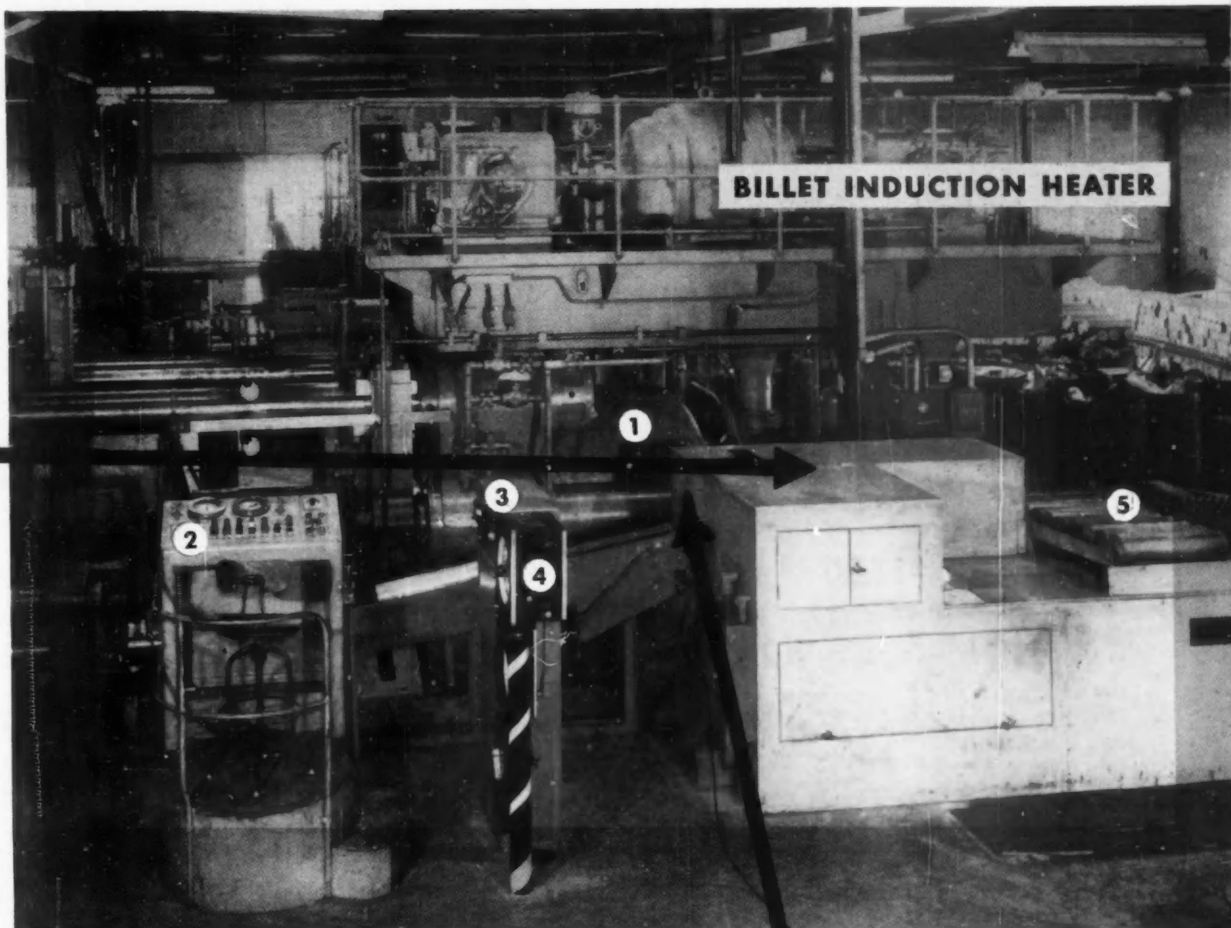
THREE CLASSES OF INDUCTION HEATERS

The higher the frequency of the alternating current fed to the work coil, the higher the concentration of current induced on the surface of the workpiece. This characteristic of the process leads to a grouping of equipment according to frequency range:

1. Low Frequency—60 cycle.
2. High Frequency—up to 10,000 cycles.
3. Radio Frequency—about 450 kilocycles.

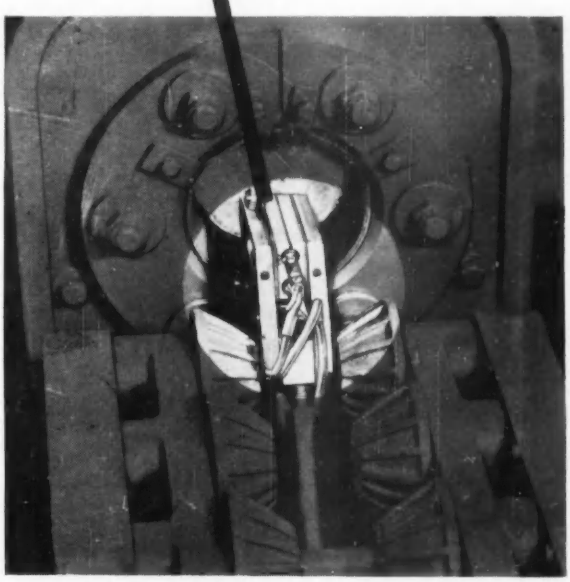
Low frequency heaters, among the first developed, are commonly used for melting and for through-heating in preparation for forging and extruding. Some furnaces handle melts up to 10 tons. Other units, such as the Magnethermic shown in Figure 1, heat billets ranging from less than ½ in. up to 3 ft in diameter. A typical circuit for the regulation of 60-cycle heaters is shown in Figure 2(a). The contactor in series with the work coil is operated by a temperature controller.

High- and radio-frequency (rf) heaters are used primarily for surface hardening and heat treating. In addition, industry is beginning to find them useful for forging, brazing, soldering, welding, sintering, and for preheating and annealing magnetic charges. An interesting example is the recent use of rf heaters for melting and pulling operations in the production of germanium and silicon crystals for transistors.



① Extrusion press
② Control console
③ Excess-temperature cut-off controller
④ Electronic indicating temperature controller
⑤ Billets

A Magnethermic 60-cycle induction unit heats billets for extrusion. Electronic indicating controller automatically brings the billets to correct temperature and then signals operator at the console that billet is ready. Fig. 1



MEASURING ELEMENT

Prod-type thermocouple (circled) measures billet temperature. Fig. 3

The high-frequency heater is equipped by its manufacturer with a timer, which opens a contactor in series with the work coil to shut off power at the end of the heating cycle. As shown by Figure 2(b), a high-frequency rotary generator supplies power to the work coil. The output of the generator is determined by a rheostat, which adjusts the current flowing through the dc field winding of the generator.

The radio frequency heater also has a timer. The work coil of each unit is designed for a specific workpiece so that in a preset time interval sufficient energy is transferred to the workpiece to heat it to the desired depth. An oscillator supplies power to the rf work coil. Continuously adjustable power for the oscillator is provided by the circuit shown schematically in Figure 2(c). Power is shut off at the end of the time interval by the opening of the power-tube grid and application of a negative bias to the tube to prevent conductance.

DIRECT TEMPERATURE CONTROL

Feedback temperature control of a workpiece is superior to indirect control because:

► Heat regulation is more uniform and more reproducible.

► Workpiece oxidation is reduced to a minimum, and heat losses are decreased. Consequently, production costs go down.

► Even heating prevents surface "hot spots," minimizing expansion and contraction, and thus prolonging crucible life.

Primary Elements

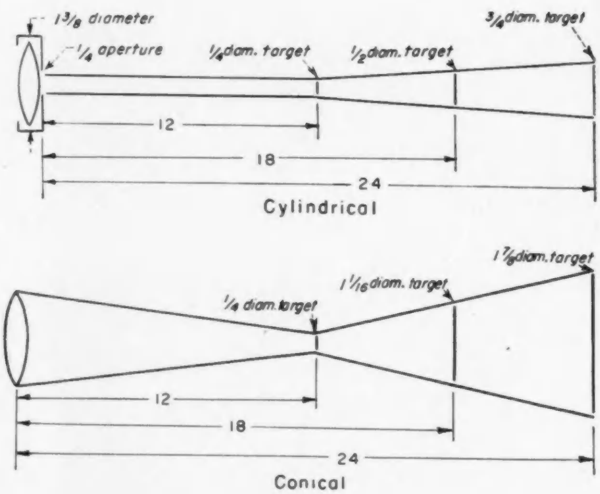
Two primary thermal elements are used: the thermocouple and the radiation pyrometer.

The prod-type thermocouple, supplied by several manufacturers of 60-cycle heaters as an integral part of their equipment, is shown in Figure 3. The end of the couple is sharp-pointed so that it can penetrate the workpiece. Most are made of heavy-gauge Chromel-Alumel wire.

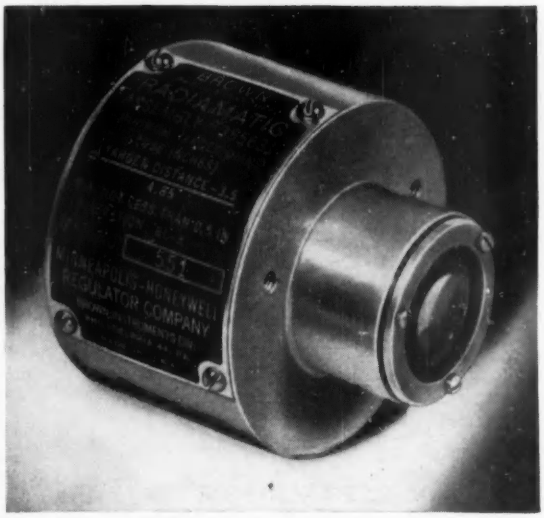
In a radiation pyrometer the heat rays emitted by an object focus through an optical system on a sensitive thermopile, which converts the radiated energy into a dc emf. The thermopile, a radial assembly of minute thermocouples wired in series, connects to a measuring instrument. Many induction heating processes demand that radiation pyrometers focus on extremely small targets. A miniature unit is shown in Figure 5. The lines of sight of a cylindrical and a conical optical system are shown in Figure 4. Some available radiation pyrometers can focus on targets as small as $\frac{1}{8}$ in. diameter and as close as 6 in.

Primary Element Application—Heating

60-cycle heaters usually have heating-duty cycles exceeding 25 seconds. So the speed of response of either a thermocouple or a radiation pyrometer is more than adequate. Prod-type couples are useful primarily for measurements where the surface emittance is too low or varies too much to make possible reproducible measurements with a radiation pyrometer. For all other applications the radiation pyrometer has gained wide acceptance, because it can make measurements without touching the workpiece. In order to use the radiation pyrometer for measuring the temperature of aluminum and low-emissivity brasses, the end of the workpiece is coated with lamp-



Application geometry of radiation pyrometers. Fig. 4



Miniature radiation pyrometer Fig 5

black. This insures excellent reproducibility of temperature measurement from one alloy to another.

Primary Element Application—Melting

Increased use of 60-cycle heaters for melting brass, aluminum, and steel has prompted the development of new wells for protecting thermocouples. Metal-Ceramic LT-1 has given excellent service in molten brass. Another new material, silicon nitride, shows great promise in tests now under way. This material has excellent resistance to attack by molten aluminum, and even molten steel if the well does not come in contact with slag.

Measuring Instruments

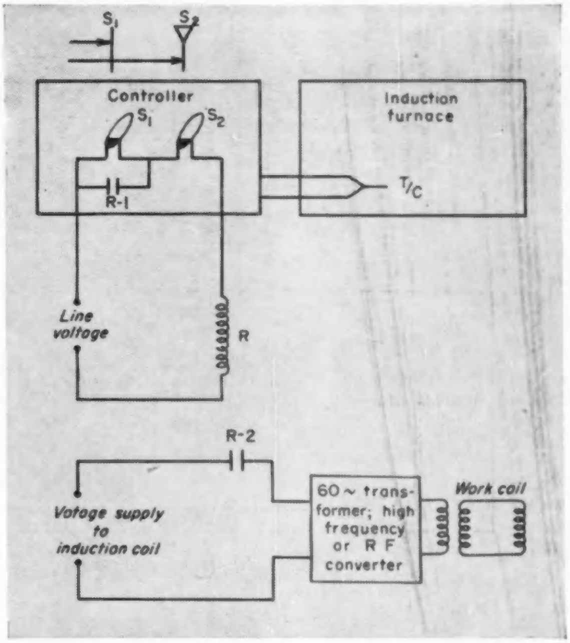
Electronic potentiometers and millivoltmeter indicators are used with the primary elements. In the past, stray currents induced in the wires connecting the primary element to the potentiometer blocked the amplifier and made measurement impossible. The problem has been overcome in the Brown Electronik potentiometer by:

▶ Adding a two-section resistance-capacity filter to the resistance-capacity damping network.

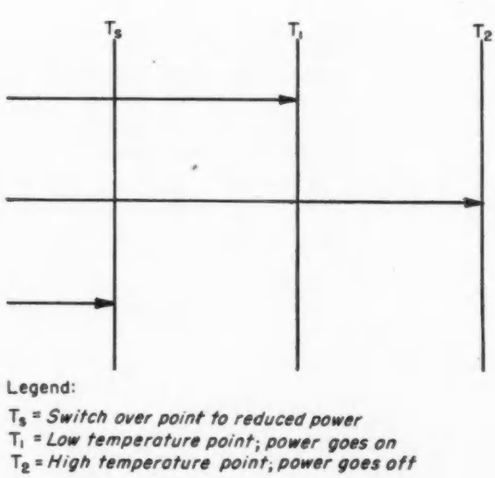
▶ Running connecting wires through grounded conduit or tinned copper shielding.

Typical Control Systems

Figure 6 schematically illustrates a millivoltmeter or electronic potentiometer with on-off control contacts, which operate a relay energizing a heating unit. The contact circuit has a differential-gap action that prevents excessive chatter and wear of the induction heater contactor R-2. This system can either heat or melt. Where melting is performed at full power and it is desirable to confine the temperature of the melt within certain limits under reduced power, a separately actuated contact is added to switch to reduced power when the holding temperature is reached. The switching sequence is shown schematically in Figure 7. Temperature T_s (point of switchover from full to reduced power) may or may not coincide with temperature T_1 (low temperature point at which power is turned on). Most users prefer switchover to occur slightly below temperature T_1. Then the differential action between T_1 and T_2 (high-temperature cut-off point) will minimize the wear of the switching contacts.



On-off temperature-control system Fig. 6

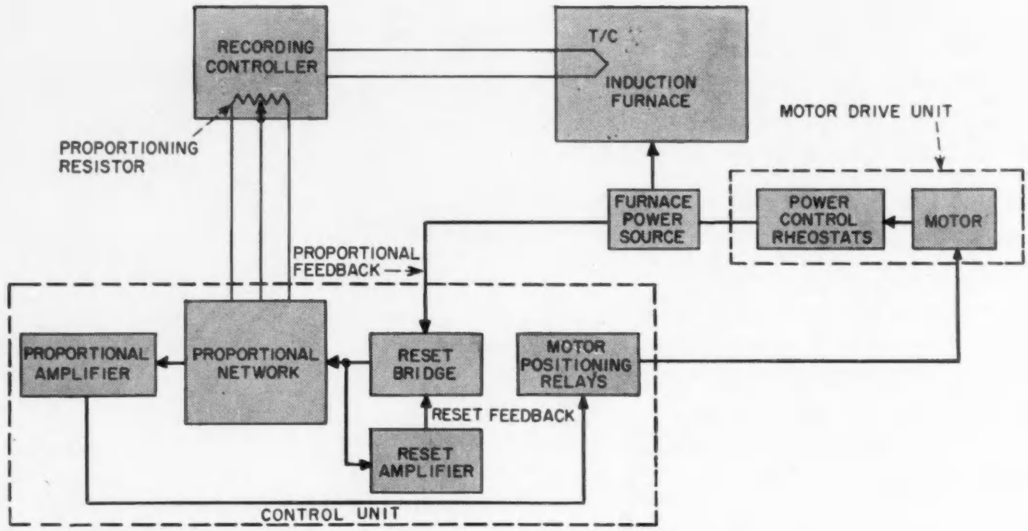


Modified switching arrangement holds work at required temperature under reduced power Fig. 7

Position-proportioning or high-limit contact temperature control is used with high frequency and rf-frequency heaters. Figure 8 is a block diagram of a proportioning control system. Proportional-plus-reset actions are produced by an integrally mounted control unit. The signal from the control unit feeds a separately mounted control motor, which drives a rheostat to maintain the temperature at the control point. Base load is set by manual power adjustment. The automatic system acts as a vernier control to compensate the load fluctuations about the base load.

INDIRECT TEMPERATURE CONTROL

High frequency and rf heaters have been controlled indirectly by limiting the duration of current flow. This method presupposes a stable power supply. A voltage regulator is effective, but size and cost prohibit its use on high power units. A practical alternative is the automatic modulation of power to the work coil in proportion to the deviation of line



Proportioning control system for high frequency and radio frequency heaters. Fig. 8

voltage or in proportion to the power deviation at the coil. Although not suitable for heaters energized by spark-gap oscillators, it is applicable to most other types including:

► High frequency heaters in which the power is regulated by the dc field excitation of the generator.

► RF heaters in which the power supplied to the work coil is varied by shifting the phase of the power supply thyratron grid voltage with respect to its plate voltage—or by varying the plate voltage of the rectifier tubes.

Primary Elements

The thermal voltage converter produces a dc output millivoltage proportional to an ac input. Available units develop 36 mvdc for a 120-vdc signal. Speed of response is adequate for the fastest heating cycles, the output rising to 90 per cent in 0.35 sec.

A pickup coil measures power when placed next to the work coil. The degree of coupling determines the pick-up coil's sensitivity to changes in work-coil power. A useable pick-up coil is made by winding as few as six turns of wire on a 1½ in. diameter form. The coil output is rectified, producing a dc signal proportional to power.

In one installation a simple pick-up coil reportedly produced temperature control to within ½ deg C at 1000 deg C. The control system compensated for line voltage changes, warmup, and changes in the firing characteristics of the thyratron power tube. Such a system works best where work temperature is much higher than ambient temperature (a temperature differential of at least 500 deg F is recommended) and where heat loss from the work to its surroundings occurs principally by radiation.

In melting applications, phase transformations of the metal may cause changes in the effective power at the work coil, even though the line voltage is steady. These applications require control based on power measurement. In case of very severe line-voltage fluctuation, a cascade system consisting of a power control reset by a temperature control is used. The cascade system used in the production of grown junction silicon and germanium crystals must maintain temperature to within 0.1 deg C at 1000 deg C.

AUXILIARY INSTRUMENTATION TO SAFEGUARD EQUIPMENT

When the temperature of the workpiece in a 60-cycle heater is measured with a radiation pyrometer, the prod-type thermocouple is useful in preventing workpiece deformation. Unless the heater positions the piece correctly, the rigidly mounted thermocouple actuates a relay which cuts the work-coil power.

Thermocouples are frequently used in melting applications to measure the temperature of the furnace lining. On large furnaces as many as 50 'couples are embedded in the furnace wall. They are connected to an electronic potentiometer which automatically scans each point of measurement and lights a signal lamp or sounds an alarm whenever the temperature exceeds the limit of safety. This warns the operator that a dangerous condition exists—for example, a break in the furnace lining—and enables him to locate the trouble spot in time to prevent serious damage to the work coil.

WHAT'S AVAILABLE TODAY FOR AUTOMATICALLY

Proportioning Solids

LAWRENCE LOWY, B-I-F Industries

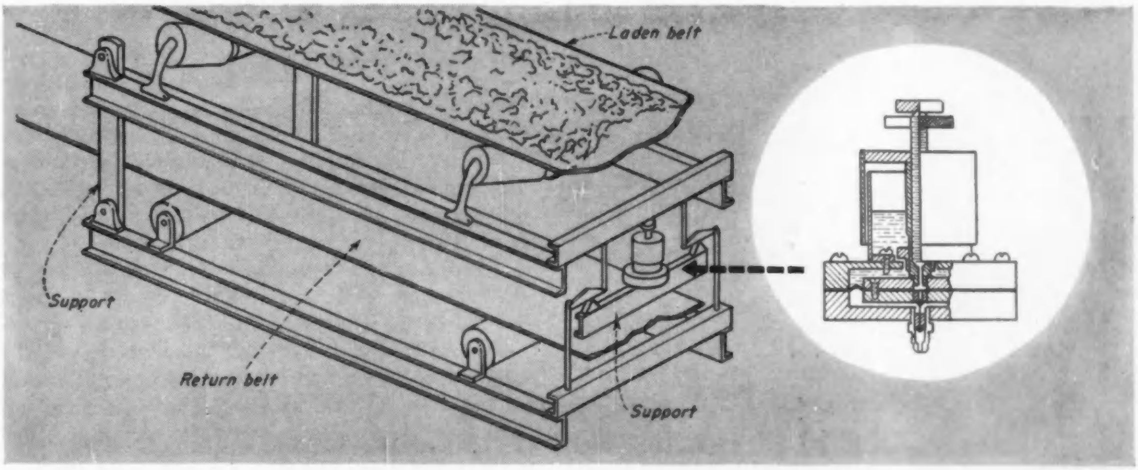
Industrial process control systems are designed to maintain continuous process equilibrium. Minimizing of disturbances is clearly the first step in this direction. Because the process feeds are an immediate source of disturbances, close regulation of feed rates is extremely important. And then, when there are a number of feed materials, process equilibrium is directly dependent on maintaining the required proportions of secondary feeds to primary feed. A measurement of primary feed rate paces the secondary feeders in accordance with the required formula.

The system may proportion liquid-to-liquid, liquid-to-solid, or solid-to-solid. Whatever the combination, the meter-pace-feed sequence is followed in all cases where proportioning is automatically controlled. Equipment for performing all phases of the sequence with liquids was discussed in the September 1954 issue of Control Engineering. This article is devoted to a description of equipment for doing the same job with solids. It is interesting to note that five of the pieces of equipment discussed employ the feedback principle. The remaining four rely on calibration or are used on jobs where accuracy is subordinate to simplicity, cost, or ruggedness.

SOLIDS METERS

One metering device determines the mass-flow rate of the solids stream by measuring the torque required to accelerate the solid particles to the tangential velocity of a synchronous motor-driven disc upon which the stream falls. The unit is restrained from rotating about the motor axis by a pneumatic force-balance mechanism. The pressure developed to balance the accelerating torque, transmitted to a pneumatic recorder-controller, establishes the command flow rate for the secondary feed.

In the solids meter shown in Figure 1, two spans, one carrying the laden belt and the other carrying the return belt, are supported at their far ends by fixed pivots. The load of the laden span is applied to the top of the diaphragm weighing unit, while the load of the return span is applied, through reversing levers, to the bottom of the diaphragm



Solids meter transmits the net weight of material on belt. Application: blending tobacco to a precise formula. Approximate cost: $8,000. Error less than plus or minus ½ per cent over a two-to-one range. Fig. 1

weighing unit. Return-belt weighing eliminates the need for tare-weight calibration and corrects for changes in belt weight due to variations in temperature, absorption of moisture, and belt wear. Operating on the force-balance principle, the weighing unit balances the differential load and thus transmits a pressure proportional to the net weight of the material carried by a length of belt equal to the length of the weigh span. A belt-speed pickup roll riding the return belt reports to a totalizing indicator, through a sprocket-and-chain drive, the length of belt which passes over the weigh span. The totalizer multiplies total belt length by weight per unit length to produce an indication of total weight delivered to the process.

Volumetric solids feeders are far more common than their gravimetric counterparts because they cost less and because they are generally more rugged.

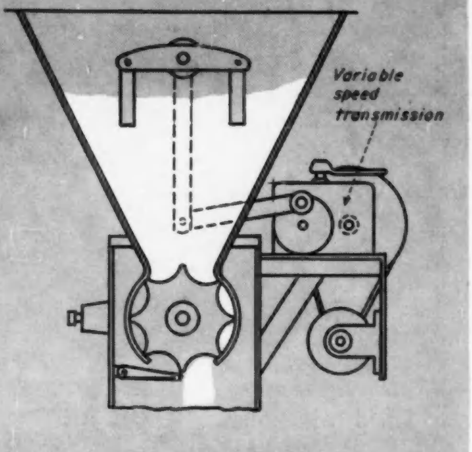
The enclosed star feeder, shown in Figure 2, is both rugged and non-flooding. Flooding is avoided by proper specification of the angle between the hopper slope and the material's angle of repose. The star is mounted below the hopper, between spring-loaded plates. Feed rates are varied by adjusting the drum's rpm. When this feeder must work against a pressure differential, the drive shaft is packed. For the more delicate and accurate operations, pockets in the drum are machined to a high finish and chrome plated. For handling corrosive materials, the rotor and housing are rubber or plastic coated.

The screw feeder is often used for granular materials. The simplified unit shown in Figure 3 uses two ratchets driven alternately by an oscillating arm with continuously adjustable stroke.

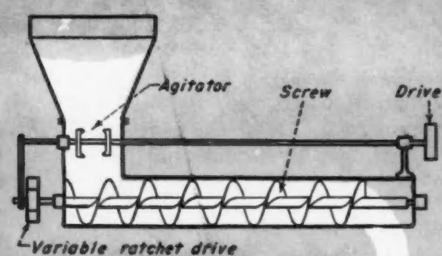
Another class of feeders moves the material by vibration. Figure 4 shows a unit driven by an electromagnet. The feeder vibrates at a natural frequency determined by its total inertia and the stiffness of powerful restraining springs. Springs of the proper stiffness make the natural frequency equal to the frequency of the current supplied to the electromagnet. In operation, the feed trough throws the material forward and then moves down and away. When the material falls, it lands slightly in advance of its previous position, and then the cycle starts all over again. The result is an almost continuous flow. This type of feeder is good for handling materials at high temperature, but free-flowing materials may flood. The magnet can be sealed and cooled.

Figure 5 illustrates a gravimetric solids feeder. A short endless belt continuously replaces the live load from the supply hopper and feeds it to the process. The entire live load is supported by the scale and balanced by the poise. Increase in the load beyond that set by the position of the poise unbalances the scale beam, lowering the control wedge between the oscillator jaw and the drive jaw attached to the feed tray. This action increases the amplitude of the tray's vibration, thereby increasing the amount

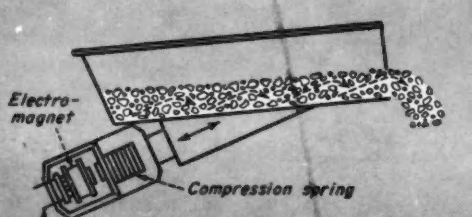
VOLUMETRIC FEEDERS



STAR Fig. 2
APPROXIMATE COST: $1,000
REMARKS: Discharge error less than ± 3 per cent



SCREW Fig. 3
APPROXIMATE COST: $700
REMARKS: Error less than ± 5 per cent



VIBRATOR Fig. 4
APPROXIMATE COST: $500
REMARKS: Error ± 3 per cent if material does not flood

of material fed to the belt and bringing the scale back to balance. Since a tray vibration amplitude of one-eighth inch produces maximum feed, the feeder responds to minute unbalances of the scale beam. The momentary contact of the oscillator jaws with the wedge suspended from the scale beam does not materially affect the sensitivity of the beam balance. A knob located at the oscillator mechanism adjusts the jaw opening for neutral beam position.

In the weigh-belt feeder shown in Figure 6, the electromagnetic vibrator replaces the mechanical vibrator. Unbalance of the scale beam closes a "too high" or "too low" electric contact, which increases or decreases the current to the electromagnet and hence alters the amplitude of the tray vibration. Again, the feed rate is corrected and the scale beam returned to balance.

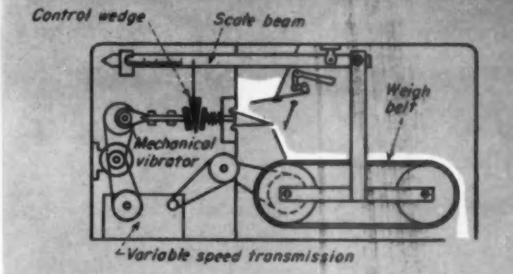
The loss-in-weight principle used for accurate proportioning of liquids is also applied to solids, as shown in Figure 7. The scale-mounted weigh hopper shown holds enough for the length of the run, although dual scale units are available for continuous operation. When one scale unit is feeding, the other is filling automatically. The scale poise is retracted at a rate proportional to the product of the primary feed signal and the desired proportion between the primary and secondary feeds. Retraction of the poise unbalances the scale and raises the resilient wedge suspended between the scale feed tray and the reciprocating drive. Consequently the amplitude of the feed tray oscillation increases, raising the rate at which material is withdrawn from the hopper. Removal of material at a greater rate returns the scale to balance.

Sudden flooding of free-flowing material must either be prevented by appropriate design of the hopper contours in solid feeders or be halted once it occurs. In the feeder shown in Figure 5, the swinging baffle at the outboard end of the feeder tray is tripped as soon as flooding takes place. Tripping of the swinging baffle starts a chain of events which causes a pneumatic cylinder to close a gate between the supply hopper and the feeder tray. In addition, alarms sound.

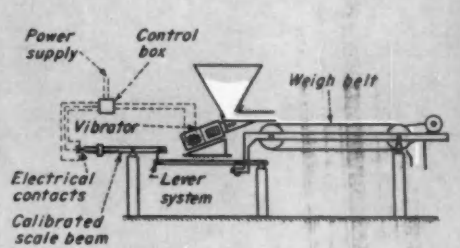
In an alternate arrangement, used when materials are known to flood regularly, a rotary feeder is placed above the vibrating tray. Stopping the rotation positively shuts off the feed. Excess material that backs up on the vibrating tray is returned by the rotor to the supply hopper.

Electronic load cells can perform many of the weighings made with mechanical equipment. For instance, beam unbalance of the weigh feeder shown in Figure 6 could be detected by an electronic load cell, and the unbalance transmitted to an elementary electronic proportional controller which would manipulate the current applied to the electromagnetic vibrator. The full accuracy of the beam balance would be used in conjunction with the extreme sensitivity of the electronic load cell.

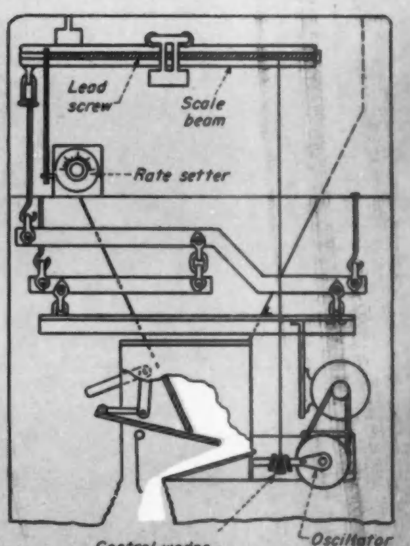
GRAVIMETRIC FEEDERS



BELT (Mechanical Vibrator) Fig. 5
APPROXIMATE COST: $3,000
REMARKS: Error less than ± 1 per cent over entire range



BELT (Electrical Vibrator) Fig. 6
APPROXIMATE COST: $3,000
REMARKS: Error less than ± 1 per cent over entire range

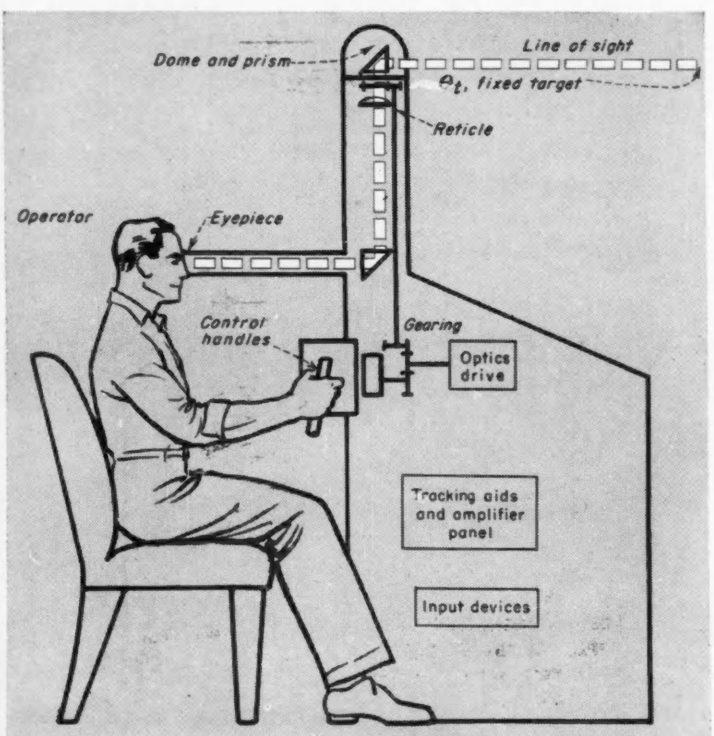


LOSS-IN-WEIGHT Fig. 7
APPROXIMATE COST: $6,000
REMARKS: Error less than ± ½ percent over entire range

THE GIST: When taking aim at a flying duck, a hunter becomes part of a closed loop that includes his gun and the duck. If he is a good shot, he can draw a bead on the duck and bring the bird down. But human reflexes aren't keen enough for today's anti-aircraft or aerial gunnery. The gunner needs electromechanical aids to help him align his sights with the target. Since the man is still part of the system, the tracking aids should fit his responses. That is, the system design should take into account human dynamics. This article, based on the author's experiments, analyses the human being as a control component. One point is that a man pointing a gun adjusts his aim with a series of almost separate movements. Thus, the electromechanical part of the system should accomodate a step-by-step input.

Man As a Servo Component

JOEL GREENE, Kollsman Instrument Corp.



SIMULATED SHOOTING

Fig. 3. A surplus sight with a servo drive at the shaft input to the dome prism simulates an optical sighting system. To simplify the analysis and operation, the elevation shaft to the dome is locked at zero degrees. Thus all results are taken in the horizontal plane, with the azimuth optics servo positioned from a resolver input order.

Looking through the reticle, the operator sees a reticle crosshair in the center of his field of vision, which encompasses about 25 deg. Sight magnification equals one. The target seen by the operator is the head of a pin on a white wall 8 ft from the dome. The white area completely fills the field of view at all times. Pinhead diameter subtends one milliradian.

To transmit the various control order from the operator's hand mo-

A PERSON AIMING at a target visually senses the error between the line of the gunsights and the target. The stimulus caused by this error activates his body and aims to align the gunsights with the target. When error converges to zero, a new order is set into motion, and his finger pulls the trigger.

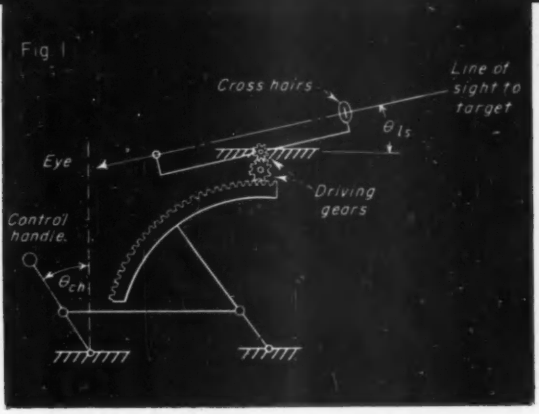
This is the simplest form of manual tracking. Here the operator is a complete closed loop system. He senses the error, furnishes the necessary power, and corrects the output until the error is zero. However, there is a limit to the power available and the rates at which an operator can move various parts of his body. In addition, the inherent time lag of the human system effects his error sensing facilities. These limitations are overcome by giving the tracker suitable aids that will meet the load specifications of accuracy, power, and motion.

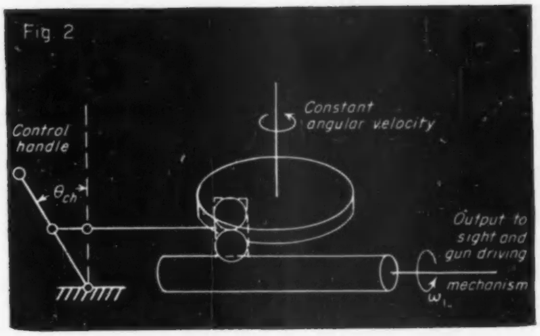
BACKGROUND

The simple manual tracking system, Figure 1, is positional. A change in angular position of the operator's controls, θ_{ch}, produces a proportional displacement, θ_{ls}, at the sight. The operator's function is to position the sight until it coincides with the line between his eye and the target. This relationship can be expressed

$$\theta_{ls} = K\theta_{ch} \tag{1}$$

With this system the operator soon becomes fatigued, and his accuracy is limited. The next step is to add hydraulic or electromechanical power drives for the guns and various types of controls and optical





Simplest manual tracking system. With no aids, sight position is proportional to control handle displacement. Fig. 1

System using mechanical integrator. Tracking rate is proportional to ball position, thus to handle displacement. Fig. 2

tion, a resolver, a potentiometer, and an induction generator are geared to the shaft handle. The resolver gear ratio is such that a 45 deg motion of the operator's hand produces a 90 deg motion elsewhere. This reduces the fatigue effect on the wrists and arms. The resolver is used in all tests where proportional response is required.

The potentiometer is used for rate control. It transmits a voltage proportional to control-handle displacement. The large gear ratio between the generator and the control-handle causes the generator to deliver a high amplitude voltage proportional to the rate of control-handle displacement. This signal is used as a positional boost in rate control systems.

When the equipment is zeroed, the reticle lies directly on the target pinhead. In positional system operation, any angular displacement of the handles causes a proportional displacement in the optics by means of the resolver transmission. A linear potentiometer geared to the azimuth servo shaft is connected to recording equipment. When the reticle deviates from the target, the potentiometer output is a dc signal proportional to the displacement. This signal is recorded and reresents the error between the target and the reticle.

During operation, an input stimulus is injected into the optics-drive null circuit. This causes the reticle to be displaced from the target. The operator, seeing an error appear, moves his controls until the reticle again lies on the target. The input stimulus is also recorded as a reference.

From the operator's viewpoint, the motion of the field of view relative to a fixed target is equivalent to the motion of a target relative to a field. The error and correction as seen on the recordings represents the closed loop response of the system, with a human element as the control source.

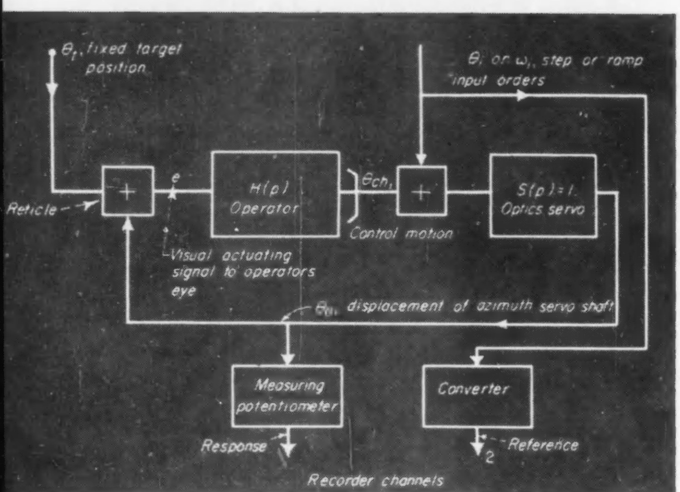
Step input orders come from a rotary switch from voltages equivalent to 1, 1½, 3, 5, 7½, and 15 deg displacements of a tapped toroid. These steps are intermixed with zero orders, varied in the positive and negative directions, and varied in the spacing between steps.

Ramp inputs from a tachometer feedback or integrating servo with a potentiometer on the output shaft. Thus a ramp voltage is transmitted into the null circuit. This servo is zeroed and energized from a switch on the handles. The ramp is made random by varying the input voltage exciting the servo. Shaft speed is controlled in this manner.

The optics-drive servo has a resonant damp and is critically damped. Its bandpass makes its time lag small compared to that of operator.

sights. The operator can now sit at the eyepiece of an optical gunsight and manipulate a set of controls. These simultaneously set the sight and the gun on the target. Geared to the controls are potentiometers, synchros, or resolvers that produce the control displacement information for the gun drive and sight.

Even with this equipment, the system is positional and still obeys Equation 1. Because of the inherent lag of the human operator, it is impossible to follow rapidly moving targets. Again fatigue and poor performance result. To solve this problem, larger fields of view, acquisition systems, and tracking aids that will produce rate- and acceleration-control systems must be used.



Block diagram of positional-control system. Fig. 4

Rate-control systems establish an output rate-of-sight movement proportional to control-handle displacement. The relationship

$$p\theta_{lo} = K\theta_{ch} \tag{2}$$

describes this type of system. Integration is necessary to produce this line-of-sight rate. One method is to use a mechanical integrator, Figure 2, in which the disk is driven at a constant angular velocity. The output rate is a linear function of ball position. Another system has a linear potentiometer coupled to the controls. With this, an input voltage proportional to position is bucked against the tachometer output of a velocity- or integrator-type servo. Since tachometer voltage is a function of shaft speed, an output rate is established that is proportional to input position.

The error in the sight is a function of the inherent time lag of the operator (which is essentially constant) and the change in velocity of the target. To overcome these errors with a pure rate-control system, a faster rate than is necessary must be initially set in. Then the controls must be readjusted to get the correct rate. Adding a positional boost improves the control system. By proper adjustment of the system parameters, a single control displacement that places the reticle directly on the target simultaneously adds the correct value of the rate that caused the error.

The fact that optical sights have no reference is conspicuous in rate-control systems. For a specific control-handle displacement, the field of view will move at some rate, usually unknown to the operator. Within the field of sight, the target will be moving at a different rate and probably will be accelerating. The operator cannot predict the target rate and must rely on his control system to get on target. As the target accelerates he will make step corrections to stay with it.

A further advancement is to incorporate a second integrator in cascade with the first. Then a control displacement will produce an acceleration in the output. While the zero position of the controls in a rate system produces a zero rate in the output, zero position in an acceleration system will produce a constant rate based on the previous information set into the equipment. Any deviation of the controls will cause a change in rate of the output shaft.

The interesting thing is to determine how the operator reacts to different types of inputs using the systems described above. To measure these visual-motor responses an investigation can be made with a simulated manual-tracking system, Figure 3. This experimental set-up permits the addition of various control inputs and tracking aids.

The usual way to compute frequency response characteristics, by observing a system's response to a sinusoidal pattern, is not valid since a man quickly catches on and predicts the sine wave. This destroys the realism of the problem. Therefore transient visual inputs are used. Where a comparison of positional and rate systems is to be made, ramp inputs are used. In all tests, the input stimuli are transmitted in randomly to prevent the operator from predicting the next input order.

RESPONSE TO STEP INPUTS— Positional Control

A block diagram of the positional control system is shown in Figure 4. The closed loop response of the operator's control motion, θ_{ch}, with respect to an input order, θ_i, is

$$\frac{\theta_{ch}}{\theta_i} = \frac{H(p)}{1 + H(p)} \tag{3}$$

Figure 5 shows a typical response as seen on a recorder. The input step θ_i causes the step displacement θ_o. After the time lag of the operator, t, he moves his controls, θ_{ch}, so that the output returns

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This article is based on part of a thesis submitted by the author in partial fulfilment of the requirements for the MEE degree at the Polytechnic Institute of Brooklyn, 1954.

to zero position (reticle and target coincide). Since the error appears to the operator as a step displacement of the target, the response to a target movement would be identical to that actually obtained by injecting an input stimulus into the null circuit.

Figure 6 shows three responses by one individual with a recorder speed of 25mm per sec. Response (A) shows the typical overshoot of the underdamped reaction. This is caused by the operators attempt to get on the target "quickly". Response (B) is the result of the operator attempting only to get on the target. With this objective the tendency is to make a fast initial response and then a slow drift to the target. Response (C) is similar to (B), but the operator was able to approach a more critically damped reaction.

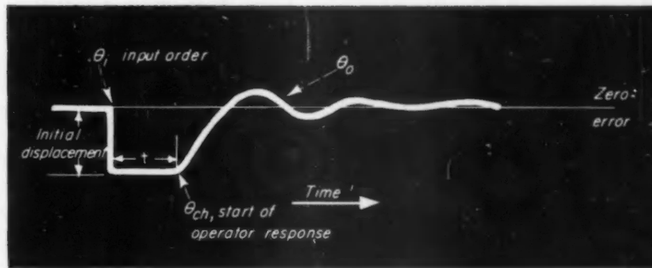
Five persons were tested, two had previously used the equipment and three had not. Of these latter, two had never tracked before and one was a former Air Force gunner. The excellent responses of the gunner substantiate the authenticity of the simulated set-up. An analysis of 130 different responses for one of the experienced trackers shows that he responded at a rate proportional to the magnitude of the step input. For magnitudes from plus or minus 1 to plus or minus 7 deg, the rate was constant at approximately 3 deg per sec of line-of-sight per degree of target displacement. At the controls, this corresponds to 1.5 deg per sec per degree step. This information can be used to determine the generator gear ratio when establishing the proper positional boost voltages in rate-control systems. The total time required for this operator to get on target was 2.1 sec (average), of which 0.5 sec (average) was the inherent lag time.

For trained operators, the lag time varied from 0.4 to 0.5 sec, while inexperienced operators took as much as 1.0 sec.

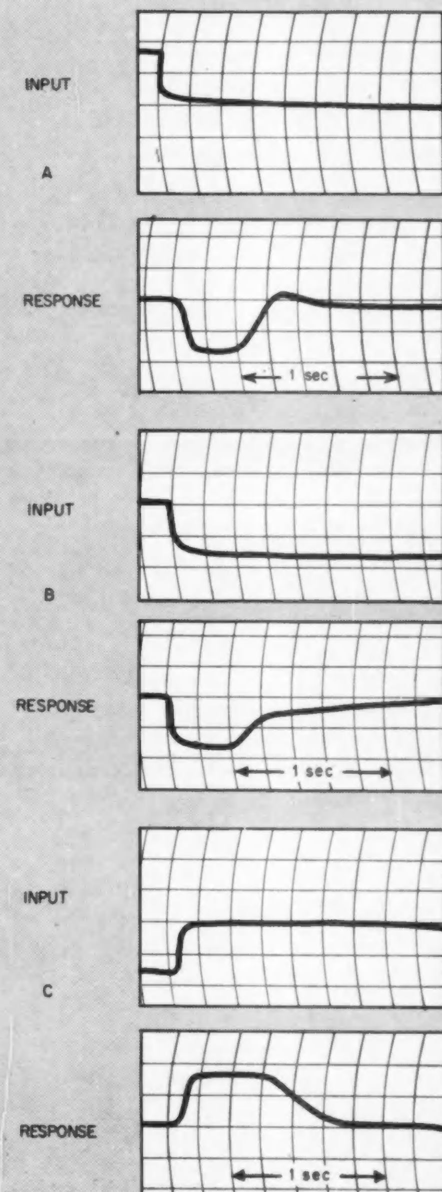
For all operators the tendency was to be overdamped. Often the operator, on approaching the target, would pull away and then drift on at a slower rate. Critically damped cases were numerous and the underdamped response with large overshoots appeared occassionally. The rise time to wipe out 90 per cent of the error varied from 0.4 sec for small displacements to 0.8 sec for a 15 sec step. This neglects lag time.

RESPONSE TO RAMP INPUTS— Positional Control

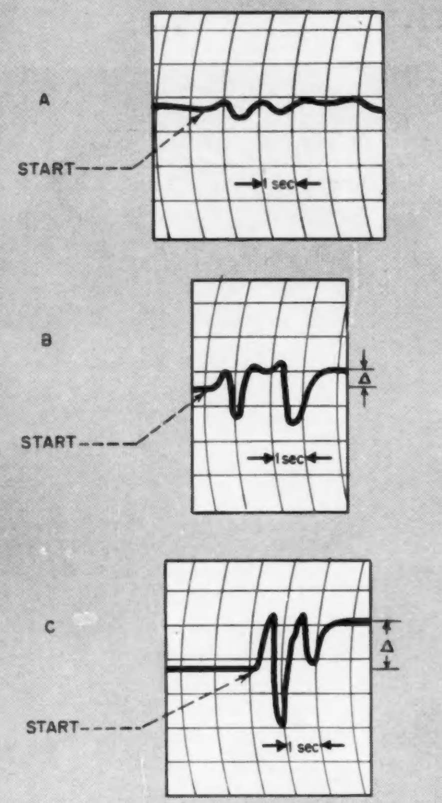
When following a ramp or rate input, the operator changes his transfer function. Figure 7 shows a typical recorded response. Until time t_1, the reticle and target are aligned. At t_1, the ramp input causes the target to move relative to the reticle at some constant rate. At time t_2, after the time lag of the operator, he moves the control handles in steps, tending to decrease the error with each step. After a few such displacements, the operator adjusts himself to target rate. Thus the transfer function changes



Typical operator response to step. Control system is positional. Fig. 5

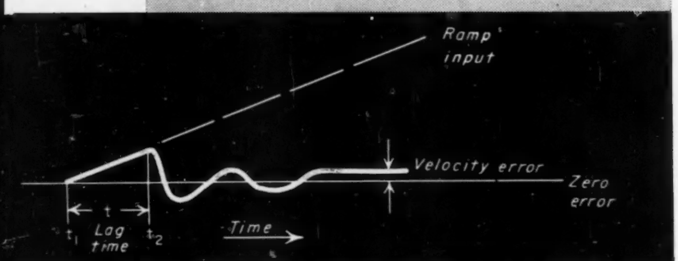


Test recordings of positional responses to step inputs. (A) Step is minus 3 to 0 deg. Response is underdamped. (B) Step is 0 to 2.8 deg. Response is overdamped. (C) Step is 2.8 to 0 deg. Response is over damped to critical. Fig. 6



Test recordings of positional responses to ramp inputs. Note increase in velocity error with rate. (A) Rate 1 deg per sec, velocity error about 0.3 deg. (B) Rate 3.5 deg per sec, velocity error, Δ, about 0.5 deg. (C) Rate 6 deg per sec, Δ about 0.5-1.0 deg. Fig. 8

Typical operator response to ramp. Control system is positional. Fig. 7



with experience as the operator tends to integrate the error. Essentially the operator changes from a positional servo to an integrator, smoothing out the error as each change is made. Actual responses can be seen in Figure 8. The time lag remains at about 0.5 sec, and a velocity error exists that increases with an increase in rate input.

RESPONSE TO STEP AND RAMP INPUTS—Rate Control

Figure 9 shows a block diagram of the system that combines rate control with a positional boost. Two control components are attached to the control handles: a potentiometer adjusted to develop plus or minus K_1 volts per deg of control displacement, and an induction generator which generates plus or minus K_2 volts per deg per sec of control motion. For a control motion θ_{ch}, the following output is obtained from the potentiometer

$$p\theta_1 = K_1 K_3 \theta_{ch} \tag{4}$$

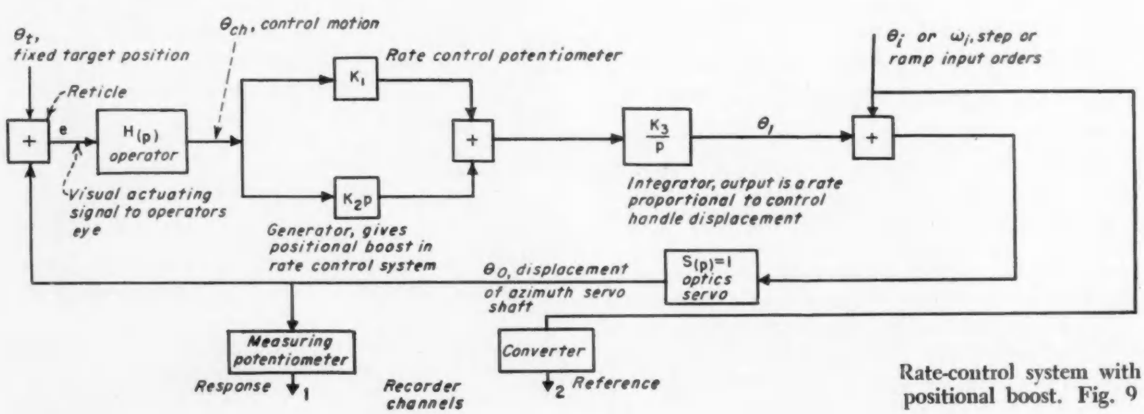
This is an output rate proportional to a control displacement. Generator output is

$$\theta_1 = K_2 K_3 \theta_{ch} \tag{5}$$

This is an output positional change proportional to the rate of application of an input displacement.

With this arrangement a control-handle displacement produces a positional boost and an output rate. A resolver on the output shaft transmits this information to the optics servo. If the system parameters are correctly adjusted, a single step correction produces the new rate required to track the target, together with the proper positional boost to bring the reticle directly on the target. The relationship of these parameters is defined as the "aided tracking" time constant. This corresponds to the time lag of the operator.

To make step corrections with this system, the operator must make a step motion away from the zero position and then a return motion to it. The boost obtained from the generator is wiped out in the return motion, but the integration of the potentiometer produces the step in the output.



Rate-control system with positional boost. Fig. 9

Figure 10 shows typical recordings for a rate-control system where the operator responds to step inputs. For more than 100 tests, the average time lag is still 0.5 sec. The time to erase 90 per cent of the error is longer because of the integration process. With no detent mechanism at the zero position, remaining on the target is more difficult. A slight deviation from zero produces a rate that must be wiped out. Rate-control systems are not intended to make positional changes.

Figure 11 shows typical error recordings for a rate-control system with a velocity or ramp input.

A comparison of Figures 8 and 11 shows the decided advantage of using a rate-control system for rate targets, and a comparison of figures 6 and 10 shows the advantage of using positional systems for positional changes. The operator's actions are less fatiguing, since only a single step displacement of the controls is required, the time to get on target is shorter, and there is no velocity error. Even with these systems the operator reacts in steps, but the higher-order rate tracking is accomplished by the integrating servo tracking aid.

What These Tests Indicate

▶ A tracking system using a human operator to close the loop requires "aids" to keep the operator's motion at a minimum at the input end, and to produce the required motion, power, and accuracy at the output end. These aids tend to increase the bandwidth of the operator, whose inherent time lag causes instability once the limits of the system are exceeded.

▶ The human operator has a changing transfer function. Based on prediction, experience, and a reference, the operator quickly adjusts his response to meet the requirements. With no reference, and no method of determining rates, the operator learns to integrate the error and change his response.

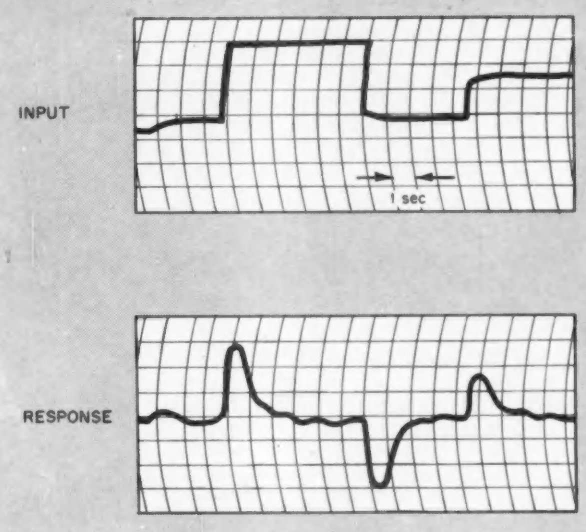
▶ Regardless of how an error occurs, an operator reacts with a step motion and at a rate proportional to the error. Since this is the normal response of an operator, the input end of the system should be designed to accommodate a step input. The aiding components should develop the higher mathematical orders of velocity and acceleration.

▶ Men of specific coordination and response characteristics will develop similar step responses, so that system operation will be approximately the same with any trained operator.

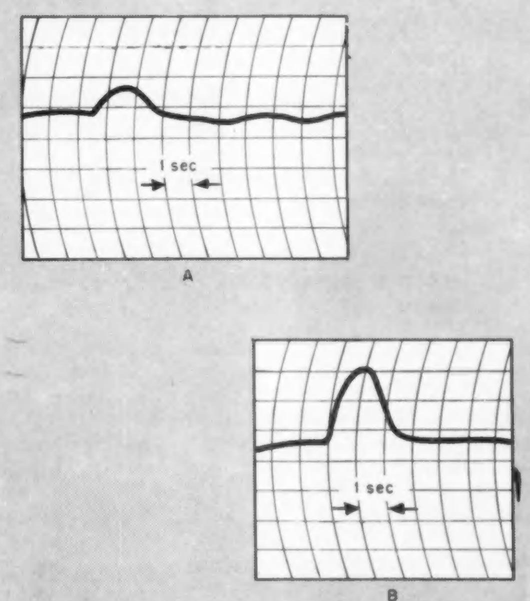
With this test set-up the transfer function of an operator using a positional control consists of a delay line cascaded with an integrator. This can be determined from his response (critically damped) to a step input by converting transient response to frequency response. The transfer function can be expressed mathematically by

$$H(p) = \frac{2.5^{-0.4p}(p + 40)}{p(p + 15.5)}$$

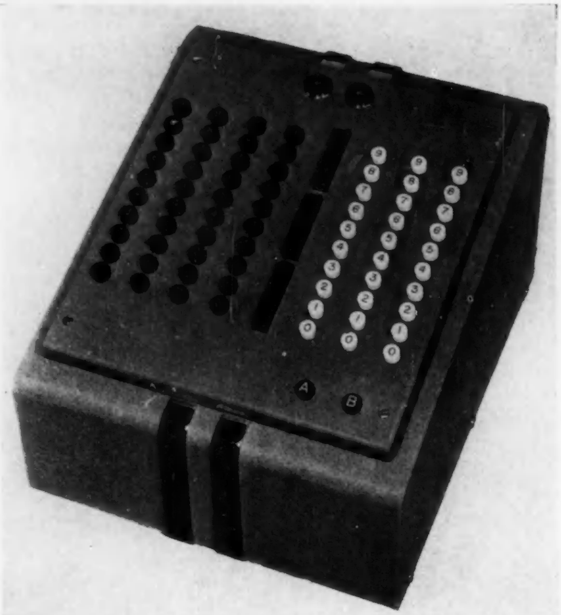
Where 0.4 is the inherent time lag.



Test recordings of rate responses to step inputs. From left to right step inputs are from 1 to 0 deg, 0 to minus 5½ deg, minus 5½ to 0 deg and 0 to minus 3½ deg. Fig. 10



Test recordings of error response to ramp inputs for rate control system. In (A) rate is 1 deg per sec, while in (B) rate is 3.5 deg per sec. Fig. 11



Pot is selected on right hand side of keyboard. Left-side keys tap a divider accurate to one part in 100,000. Fig. 1

Clutch drives keyboard-selected pot from shaft which is servo-driven by difference in keyboard and pot voltage. Fig. 2

Keyboard System Makes Pot Setting Simple

Setting a couple of hundred potentiometers on an analog computer need no longer be a day-long headache. This system is fast, accurate, and as easy to use as an adding machine. Nonlinearities of loaded pots don't faze it.

LLOYD L. GORDON, Electronic Associates, Inc.

As engineering trends in modern analog computers continue towards complexity and higher accuracy, the problem of the operator becomes more and more pronounced. The modern analog computer contains many dc amplifiers, resolvers, multipliers, and associated equipment. The number of potentiometers used as two-terminal networks and for initial-condition storage in computers has grown fantastically.

Individual computers using 1,000 or more potentiometers are now being built, and some are already in use. The time-consuming job of setting these potentiometers has been a subject of considerable discussion and some development work.

Our approach to a solution for this problem was to design and produce equipment that could be controlled by a keyboard, which would select and set the potentiometers rapidly and accurately even under loaded conditions. The design objective was to produce a unit that could be economically manufactured and would be accurate, simple, rugged, and dependable.

GENERAL DESCRIPTION

A reference voltage supply feeds to the keyboard unit, which contains a precision resistance divider accurate to one part in 100,000. The output of this divider feeds to one input of a chopper-type amplifier. The other input of this servo-amplifier comes from the potentiometer arm through the control chassis. The null-seeking servo system will run until the voltage difference between the precision resistance unit and the arm of the potentiometer is zero. Then control circuits clear the system, making it possible for the operator to proceed to the next operation.

Figure 1 shows a typical keyboard used in the equipment. The left section of the keyboard controls the precision resistance divider unit. The right section controls the selection of any one of a 1,000 relays in a matrix circuit each corresponding to one potentiometer. The center bars control the operations performed by the equipment. The operator has a choice of setting a potentiometer, clearing the equipment, or connecting an external readout instrument that deter-

mines the value stored in the selected potentiometer.

The red and green pilot lights at the top of the keyboard tell the operator when the setting operation has been completed to the required accuracy and the system is again ready for instructions. The green light is on when the system is not in use. After the operator selects a resistance value and the proper potentiometer and presses the "Operate" bar, the red light comes on and remains lit until the potentiometer has been adjusted to closer than .01 per cent against the resistance standard. At that time the system automatically clears, the red light goes out, and the green light glows again.

MATRIX

Figure 3 shows the corner of one plane of the matrix used in the equipment. The base plane connects to the keys in the hundreds column of the keyboard. When a key in the hundreds column is depressed, the selected base plane is connected to ground.

The vertical planes running from left to right represent the tens planes. When the keys or switches connected to these planes are in the unoperated condition, these planes are grounded. When one switch is operated, the plane associated with it is connected to plus 90v, with minus 90v being connected to ground. This applies voltage to all of the relays connected to this plane through their resistors.

In a full matrix of 1,000 relays, one for each pot, 100 relays are connected to any given tens plane. Since the resistor value is equal to the relay coil resistance the relays receive only half voltage, which is not enough to operate them.

The planes running from front to rear are the units planes, which are connected through individual resistors to the associated relays. When the units keys are in the unoperated condition, the planes are connected to ground so that all resistors connected to this plane are grounded, placing those resistors in parallel with the relay coils. When any units button is depressed, the plane connected to this button is transferred to plus 90v, and the relays and resistors in the circuit divide the voltage equally, each getting half of the total voltage.

Since the relays require 60v to operate, no relay is operated except the one at the juntion of the selected tens, units, and hundreds planes. As an additional safety factor, each relay connected to the selected tens and units planes has its opposite resistor connected to ground. This means that only one-third of the total voltage appears across the unwanted relays.

The pot relays, clutch coils, and associated potentiometers are grouped on chassis in groups of 18, along with a bus relay, one servomotor, and a gear box. Each chassis is wired to form a sub-matrix, and when these are connected in the rack or other mounting equipment, the full matrix is formed. All chassis are identical and are completely interchangeable.

The bus relay is in series with the clutch coil and is operated when any potentiometer on a given chassis is selected. It serves to connect the input and output of the servo-amplifier to the chassis containing the selected potentiometer.

CLUTCH MECHANISM

Figure 2 shows a cutaway of the clutch mechanism. It can be seen that the potentiometer is assembled with a special casting and electromagnet coil concentric with its shaft. This is the magnetic assembly, all the metal parts of which are fabricated from Armco iron. The assembly is completed when a flexible disc is placed adjacent to the gap formed between the wheel of the assembly and the casting that surrounds the magnet coil. In this gap the magnetic lines of force exist in greatest concentration.

When the coil is not energized, the flexible disc with its soft iron rim rotates approximately $\frac{1}{16}$-in. from this gap. When the magnet coil is energized, the disc is drawn over, and the magnetic iron rim comes in contact with the wheel assembly fastened to the potentiometer shaft. Magnetic seizure transmits motion of the flexible disc to the wheel and thus to the pot shaft. When the clutch coil is deenergized, the flexible disc springs away without disturbing the position of the wheel and arm of the potentiometer.

Most of the parts used in the clutch assembly are either precision castings or stampings, making it possible to manufacture this unit at a relatively low cost.

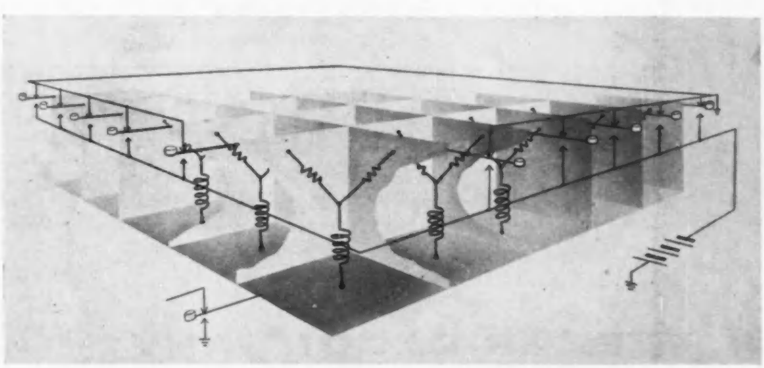
The construction of the clutch mechanism, as illustrated, makes it possible to transmit 15 in.-oz of torque when powers of approximately 8w are used in the magnet coil assembly. Pull-in times vary, depending on the power in the clutch coil and the spacing between the flexible disc and the magnet pole pieces. With 8w of power in the clutch coil and a disc-to-pole-piece spacing of $\frac{1}{16}$ in., the elapsed time from application of voltage to the engagement of the clutch is approximately 15 millisec. When the spacing between the flexible disc and the pole piece is decreased to $\frac{1}{64}$ in., the pull-in time decreases to approximately 6 millisec.

Once the clutch engages, it does not slip until the torque limit is exceeded. Changing parameters can expand the torque limit over wide ranges, and redesigning the flexible disc assembly could increase operating speeds.

SERVO AND DAMPING

Error rate damping stabilizes the servo. Designers of this unit investigated various degrees of damping. They built a critically damped unit and ran accuracy curves. Results of the tests indicated that it was desirable to have an underdamped condition in which the potentiometer would make one or two overshoots in order to attain the maximum accuracy.

The servo-amplifier has an open-circuited gain of about 600,000. About 12 db of negative feedback is



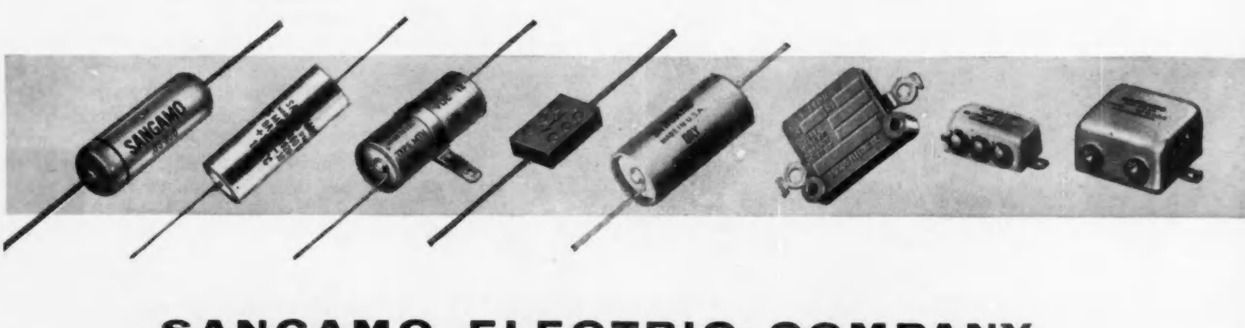
Matrix used to select 1,000 pots with 30 buttons. Fig. 3

...that's why IBM uses Sangamo

The amazingly complex IBM "702" electronic calculator is hailed as the fastest and most flexible commercial data processing system ever devised. The central Arithmetical and Logical Unit performs calculations and makes decisions at a rate of more than 10,000,000 operations in an hour. Data and instructions for processing are stored in an electrostatic memory bank of cathode ray storage tubes. Output can be in the form of punch cards at the rate of 100 per minute.

A machine like this needs components that assure maximum performance to meet its exacting demands. That's why several different types of Sangamo Capacitors are used in the 702.

If you need capacitors for demanding electronic applications, Sangamo engineers can help you. You can choose from a complete line of paper, mica, electrolytic and button type capacitors for every industrial, electronic, and radio application.



SANGAMO ELECTRIC COMPANY

MARION, ILLINOIS

used. In use the loop gain is approximately 1,000.

ACCURACY PERFORMANCE

Performance data was derived from readings taken on 324 pots. The pots were set to various values by means of the keyboard system, and then an external resistance standard and galvanometer were used to verify the settings. The accuracy of the test equipment was better than one part in 100,000.

The error curve approaches a Gaussian curve. But there are noticeable differences at plus three and minus 3 parts per 100,000. This is caused by the resolution of the pot. Since the potentiometers are wound with 18,000 turns of Jelliff 45 alloy wire for maximum temperature stability, the resulting resolution of six parts in 100,000 means that if there were no other errors in the system the resolution curve or accuracy curve should be a rectangle six parts wide. However, due to friction, noise, etc., the curve assumes the familiar Gaussian probability form.

As might be expected, with the amplifier gain reduced to 600, the spread of the error tends to increase, but again the type of distribution approaches a Gaussian curve. Curves were taken on two different pieces of equipment and with several different chassis as well as different keyboards, amplifiers, etc.

An analysis of the curves taken with the gain set at 1,000 indicates that the root-mean-square error is 3.42 parts in 100,000. When the gain is decreased to 800, the rms error increases to 3.81 parts, and with a gain setting of 600 the rms error is slightly more than four parts. Satisfactory operation was obtained with loop gains as low as 200 and as high as 1,400. At the higher loop gain setting, however, the variations in gear boxes become very pronounced and the tendency to hunt becomes difficult to control by simple damping networks.

If higher accuracy is desired, a two-stage damping network could be inserted to produce the proper lead conditions, and operation with loop gains as high as 2,000 or more could be obtained before actual hunting between the turns of wire becomes excessive. Since the linearity slope of the potentiometer has its effect on the loop gain, the operation of the equipment under these conditions will depend to a certain extent on the linearity. Some trouble in the early tests was due to variations in linearity. The potentiometers should have a rate of change of about 28 parts in 100,000 per degree of rotation. Actual tests have shown that this will go as low as 8 to 10 parts and as high as 50 to 60 parts, resulting in a variation in loop gain by a factor of 5 or 6. This effect will cause trouble at high gain.

Dr. Pepper Nips Its Froth

MILTON K. MACK, Dr. Pepper Co.

Author Mack gages water purity with bench model recording polarograph.

EDITOR'S NOTE: *This unusual use of the polarograph to reveal pesky surface-active agents which cause foaming in carbonated beverages suggests broad possibilities in industry. Certainly the foaming problem is not confined to bottling plants. And certainly many control engineers would welcome new ways to gage the efficiency of plant water-treating systems.*

One of the nagging, subtle variables in soft drink bottling—as in many other processes—is the presence of trace materials in supposedly highly purified water. To spot these traces we have developed a quick and sensitive test using a recording polarograph.

Actually, the offender, in our case, is surface-active material, which causes foaming during bottle filling, even when under 0.5 ppm in concentration. To measure these minute traces we modified the approach taken by Ivan Vavruch for refined sugar (Reference 1). This method depends on the quantitative suppression by surface active material of the maximum height of an oxygen-in-water polarographic curve.

First a standardization curve must be prepared to show relationship between amount of electrolyte present and magnitude of the oxygen maxima. This is necessary since the maxima depend on individual instrument characteristics, such as mercury drop time, mass, and temperature.

We prepared our curve using distilled water containing various salts, including calcium chloride, magnesium chloride, sodium carbonate, potassium sulphate, and sodium hydroxide. All gave essentially identical curves when conductivity was plotted against unsuppressed oxygen maxima.

Hence, at present, our results show what an unsuppressed oxygen curve would be at the conductivity of water being tested as against the actual suppression. If desired, this could be stated as percent suppression.

In our work we have been using a Sargent Model XXI polarograph and an Industrial Instruments Conductivity Bridge, Model RC 1B. The determinations have been made with a mercury drop time of 3 sec. and a temperature of 25 deg C. (1) Analytical Chemistry, July 1950.

How to Counteract Weigh-Belt Feeder Lag

WALTER C. SAEMAN, Olin Industries

Weigh belts control the feed rates of solids to many continuous processes. Common practice follows Figure 1. Under steady-state conditions the automatic load-control system presents no unusual problems. The load cell immediately senses variations in the total weight of material on the belt, and automatic changes of the screw feeder speed restore the balance.

But when a change in the load-controller set point introduces a new feed rate, a large excess or deficiency of material is delivered to the belt to keep it in balance. The result is severe disturbance to the equilibrium of the process. Happily, no more than elementary calculus is needed to analyze the dynamics and determine the correct time-program for shifting the set point of the load controller.

A case in point involves an unusually long belt-residence-time of 30 min. The belt travels at constant speed. The component of load due to the dead weight of the assembly is constant, while the remainder, due to live load, varies. Assuming that the material is uniformly distributed across the width of the belt, the live load before a shift in set point is:

$$R_s = \int_0^L X W_s \, dx = \frac{L^2}{2} W_s \qquad \text{Eq. 1}$$

where R_s = live-load, ft-lb
L = belt length, ft
W_s = unit belt load, lb per ft
X = distance from discharge, ft

The profile of the material when the load is shifted correctly to establish a new feed rate is shown in Figure 2. The live load now is:

$$R_s + \Delta R = \int_0^L X W_s \, dx + \int_{L-S}^{L} X \, \Delta W \, dx$$

where S = distance of incremental section of new load from feedpoint, ft
ΔW = change in unit belt load, lb per ft

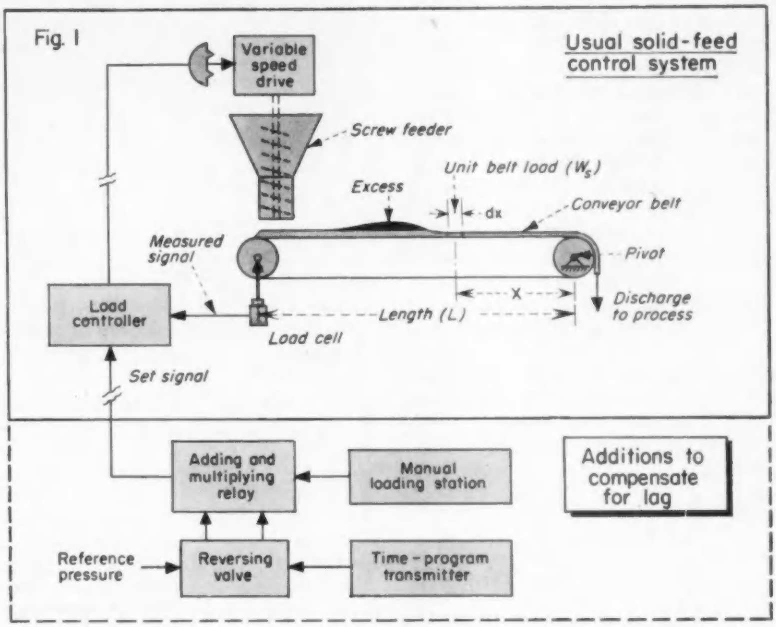
Integrating,

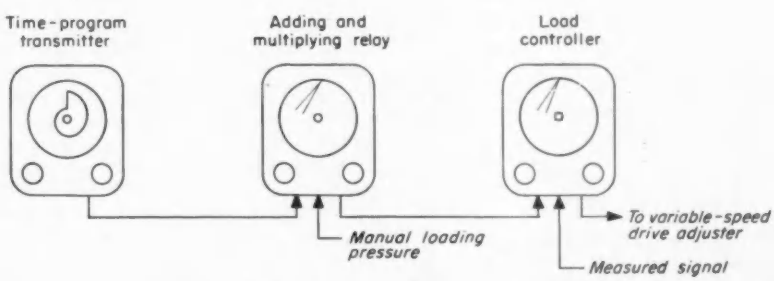
$$R_s + \Delta R = \frac{L^2}{2} W_s + \frac{L^2}{2} \Delta W - \frac{L^2 - 2LS + S^2}{2} \Delta W \qquad \text{Eq. 2}$$

Subtracting Equation 1 from Equation 2 to find the change in load;

$$\Delta R = \Delta W \left[\frac{L^2}{2} - \frac{L^2}{2} - \frac{S^2}{2} + LS \right]$$

$$= \Delta W \left[LS - \frac{S^2}{2} \right] \qquad \text{Eq. 3}$$





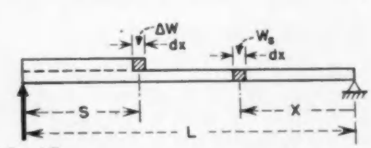
A conventional controller with pneumatically positioned set point is the control station in a weigh-belt lag compensating system. Fig. 3

Because $s = vt$, where v = belt speed, and $L = 30\,v$,

Equation 3 becomes

$$\Delta R = \Delta W v^2 t \left(30 - \frac{t}{2}\right) \qquad \text{Eq. 4}$$

Equation 4 is the program that the load controller's set point must follow to shift the feed rate of material without sustained excess or deficiency.



Profile of material on the weigh-belt when the load is increased correctly. Fig. 2

Zero-point adjustment of a conventional controller compensates for dead weight. The problem, then, is to translate Equation 4 into hardware. Because v is constant, components need handle only the expression $\Delta W t(30 - t/2)$. With minor modifications, conventional pneumatic instruments and components can do this. Figure 3 shows how. From a cam with a fixed profile the time-program transmitter develops a pressure proportional to $t(30 - t/2)$. The multiplying factor ΔW can have any value, positive, negative, or zero. So rather than cut a large number of cams with different profiles, the signal developed by the time-program transmitter is passed through either of the multiplying "relays" shown in Figures 4 and 5. There

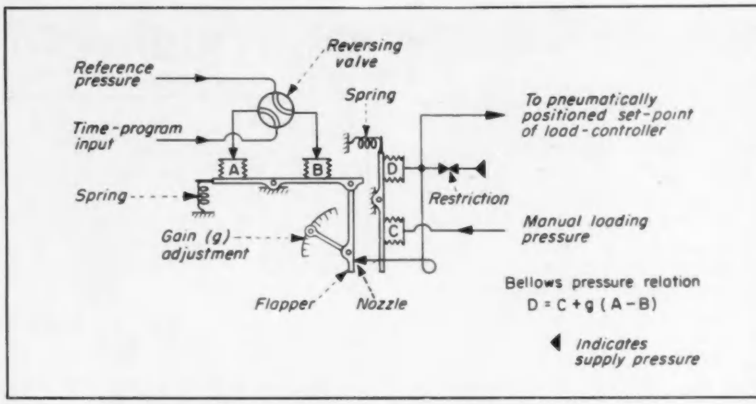
the effectiveness of the signal is determined by adjusting the relay gain. A manually adjusted signal is added and the total, $\Delta W t(30 - t/2) + C$, transmitted to the pneumatically driven set point of the load controller.

Each multiplying unit is constructed from a controller mechanism. Its proportional band is adjustable to infinity (zero gain), while what is usually the "reset" bellows becomes a means for adding the manual bias. The signal from the time-programmed unit is reversed by switching between opposed relay bellows. A separate regulator maintains the zero-level pressure within the opposing bellows.

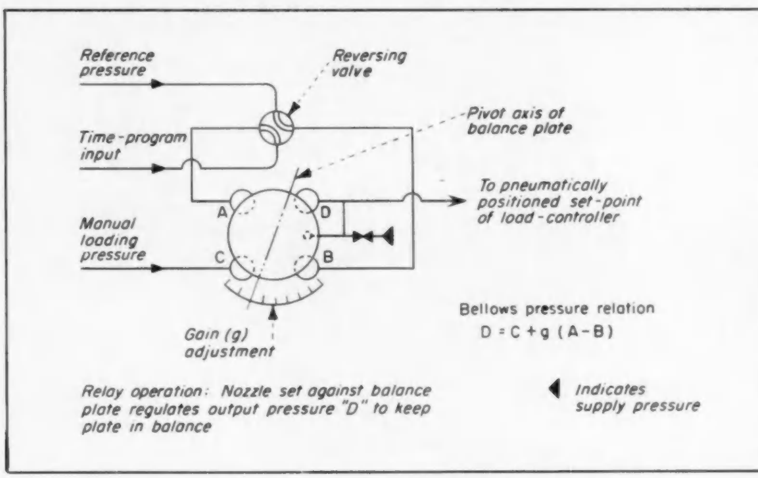
The valuable design features of the relays used in this application are 1) calibrated scales for convenient gain adjustment, and 2) the gain stability of the mechanical leverages.

Changing the feed rate involves this sequence:

1) Operator starts the time-program unit.
2) He shifts relay gain from zero to the value proportional to ΔW.
3) The program unit stops itself at the end of the 30-minute cycle and holds the final output pressure.
4) Operator isolates the time-program unit by shifting the relay gain to zero and immediately restoring the output pressure of the weight controller by readjusting the pressure from the loading station.



Schematic diagram of motion-balance multiplying relay. Fig. 4



Schematic diagram of force-balance multiplying relay. Fig. 5

EDITOR'S NOTE: *How would you solve the problem? Suppose the rate of change of set load, instead of the change of set load, were programmed.*

change, $$\Delta R = \Delta W v^2 t \left(30 - \frac{t}{2}\right)$$

rate, $$\frac{d}{dt}\Delta R = \Delta W v^2(30 - t)$$

The rate program (first power of t) is easily established with a timer or integrator. The entire control system is now based on rate of change of load.

Can you think of another solution?

Computer Circuit Finds Peaks Automatically

BERNARD FARBER,
The W. L. Maxson Corp.

Analog computers are often required to solve problems which may be characterized as single-valued functions of one variable having a peak solution. Figure 1 illustrates the problem.

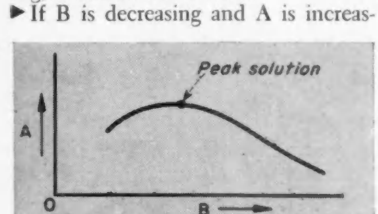
Described below is a system that automatically searches in B and finds the peak value of A. The system will operate equally successfully in locating a minimum value of A.

Let us define B as the independent variable and A as the dependent variable. Let us also assume that A is a quantity displayed by a counter or dial driven by a servo, while B is stored information that can be searched by some device driven by a mechanism or motor that is reversible.

OPERATING CONDITIONS

The operation of the system, to find automatically the maximum value of A as a function of B, is fully described by the following set of conditions:

- ►If B is increasing and A is increasing, B continues to increase
- ►If B is increasing and A is decreasing, B reverses to decrease
- ►If B is decreasing and A is decreasing, B reverses to increase
- ►If B is decreasing and A is increas-

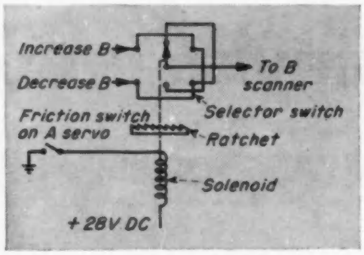


System finds maximum value of A, when A is a function of B. Fig. 1

ing, B continues to decrease

Let the servo that calculates A drive a friction switch, which is open when the servo is driving in the direction of increasing A and closed when the servo is driving in the direction of decreasing A. The closing of the switch indicates an undesirable condition, as examination of the operating conditions indicates. In Figure 2 the switch closing is used to reverse the A-servo motion. Closing the switch actuates a solenoid which drives a selector switch through a ratchet. The ratchet prevents the selector switch from stepping backward and advances it one position every time the solenoid is actuated. Alternate positions of the selector switch bring the arm of the switch in contact with signals that cause B to be scanned in opposite directions. Thus at each step of the selector switch a signal of opposite phase is applied to the B-scanning mechanism causing it to reverse its direction.

Increasing A is a desirable condition. As long as B is being scanned in a direction to yield increasing A nothing disturbs the B-scanning mechanism. If the peak of the curve is passed however (see Figure 1) then A begins to decrease. Immediately the contacts of the friction switch close. Thereupon the solenoid is actuated, the selector switch is stepped to the next position, and the signal driving the B-scanning mechanism is reversed in sign. This causes a reversal in the B-scanning direction. A, which is a function of B, begins to increase, causing the friction switch contacts to open. This releases the solenoid and it is snapped back into its unactuated position by a spring. The ratchet prevents the selector switch from returning to its original position and the B-mechanism continues to scan in its



Switch on A servo closes when A is decreasing, reversing B scan. Fig. 2

latest direction until a decrease in A again initiates the sequence.

This system will track the maximum point of the curve shown on Figure 1 and upon finding it will hunt about it. The tighter the computing system used to find A as a function of B, the smaller the amplitude of the hunting about the maximum.

This system has one fault. A stray pulse or transient in the A-computing system may disturb it. For example, if when A is decreasing, a transient signal should cause A to increase momentarily, the solenoid would relax. Then, as the transient passed and A decreased to its current value, the solenoid would once more be actuated, and this time the selector switch would cause a reversal in direction of B-scanning. But this B-direction calls for decreasing values of A, causing the A-servo to hold the friction switch closed. This keeps the selector switch actuated, and the same signal phase applied to the servo. Accordingly, the B-scanning mechanism will drive to one end and remain there until some accident corrects the situation.

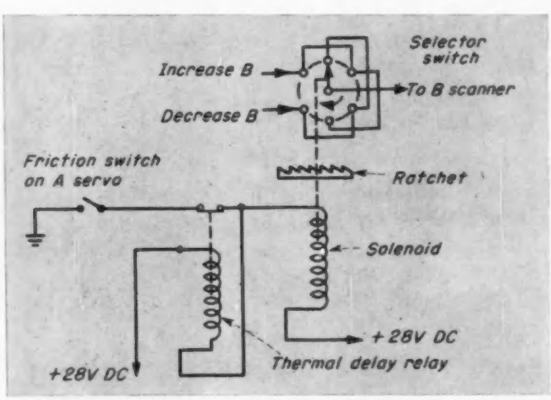
SAFETY CIRCUIT

A circuit was developed to prevent the system from going astray. The function of the safety circuit is to detect malfunction of the B-scanning operation (i.e., continuous scanning in a direction leading to decreasing values of A) and correct it by reversing the scanning direction.

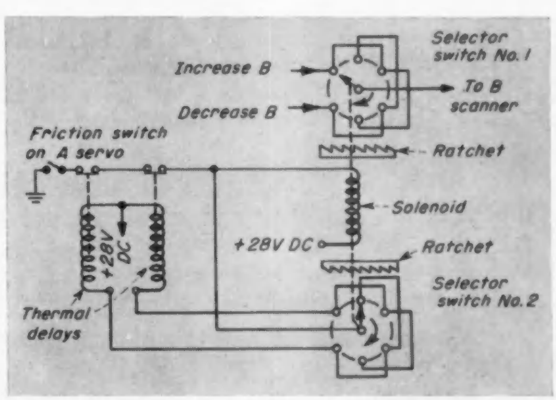
In the circuit of Figure 3, when the friction switch is closed (by A-servo motion in decreasing A-direction) it not only steps the solenoid but also energizes the thermal delay. If the system is operating properly, the stepping of the solenoid reverses scanning direction, which should lead to increasing A-values. The friction switch opens, stopping the heating up of the thermal delay relay; so the relay remains closed and has no effect on the max-seeking system. If, however, a malfunction occurs, and the B-scanning is in a direction that continuously decreases A values, then the friction switch remains closed, and after a short time the thermal delay relay de-energizes the solenoid itself. When the solenoid is de-energized nothing happens. However, as the thermal relay cools, its contacts close again and, as the A servo is still driving in the direction which keeps the friction switch closed, the solenoid now steps the selector to reverse B-scanning.

FINAL DESIGN

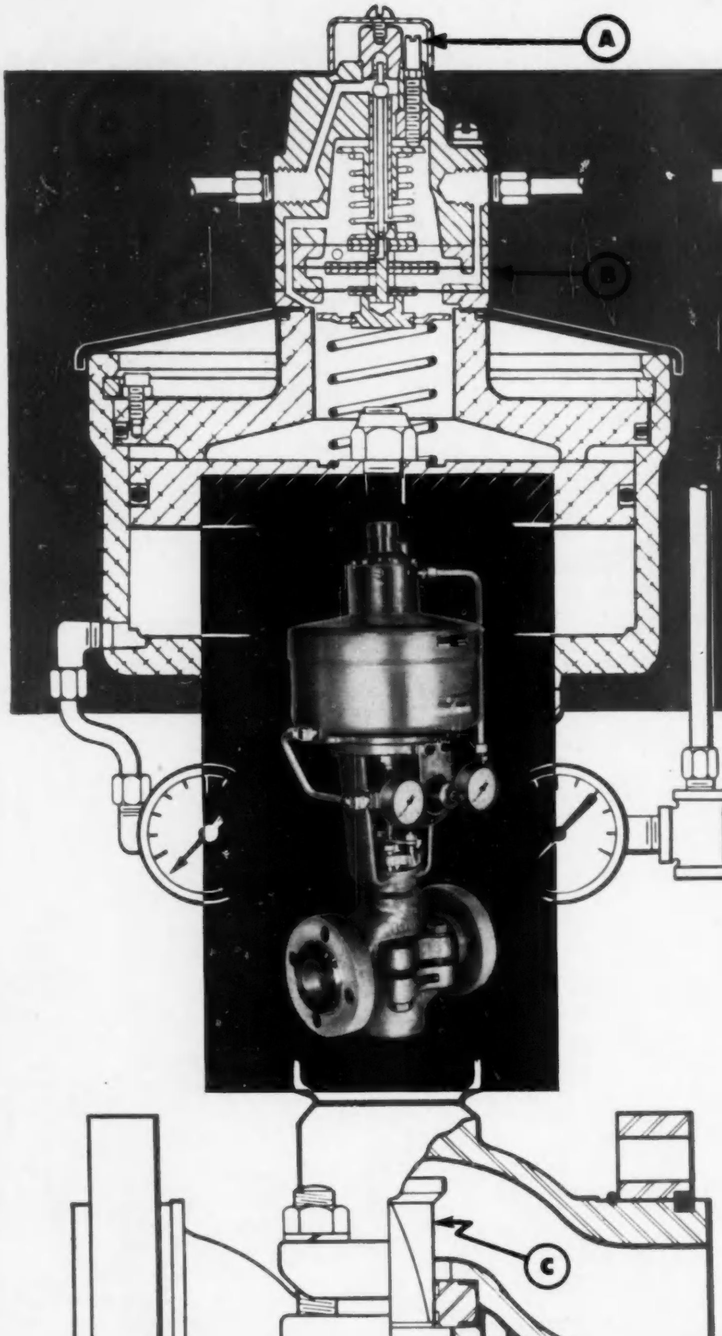
The circuit actually used requires a slight further modification. As the thermal relay heats up the first time, it introduces a previously determined delay before operating. When the relay is heated up, however, it must be given enough time to cool before it will yield the same delay time on reoperation. The circuit of Figure 3 indicates that as soon as the contacts of the thermal relay close after its first operation, it again begins to heat up. This second heat time before the relay operates will generally be too short to allow the A-servo to reverse



Delay operates only if A is decreasing longer than required to reverse B (i.e., if selector switch gets out of phase). Fig. 3



Second thermal delay is substituted for the first to allow first to cool and insure sufficient delay time. Fig. 4



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and open the friction switch. Thus an oscillatory condition of the thermal delay relay is possible. To prevent this, two thermal delay relays are used (see Figure 4). The second one substitutes for the first as soon as the first operates. Since the second thermal relay is cold, there is enough time for the friction switch to be opened. When the friction switch is opened, both thermal delays cool.

The spring-actuated return motion of the solenoid steps the second selector switch to substitute the cool thermal delay for the hot one.

LIMITATIONS

▶ For computers that employ the automatic maximum-seeking system described above, the computing time cannot be any faster than operating time of the solenoid switch. The solenoid introduces about 50 millisec. of delay. In most analog computers the servo-slewing rates are such that the switch operation is comparatively instantaneous, and the limiting factor in computing time is not the solenoid delay.

▶ Because the computations lag behind the instantaneous solution in many analog computers, B-scanning in the direction leading to decreasing A-values must be permitted for a short time (often several seconds) before corrective action is taken. This insures that a malfunction condition rather than a normal computer-lag condition prevails.

▶ Malfunction is prolonged a bit by the time taken for the thermal delay to cool down enough for its contacts to close again.

This explanation concerned a static problem, but the maximum-seeking system will work equally well for the dynamic case where the peak A-value occurs at different B-values as time progresses. So long as the curve has only one peak and the rate at which it moves does not overtax the ability of the seeking mechanism to follow it, the peak finder will track it.

It is true that the max-seeking operation is also definable as a differentiating operation. In computer work, however, we usually mean differentiation with respect to time whereas the max-seeking system differentiates with respect to another variable. Furthermore, the rate at which the differentiated signal varies is well below the satisfactory operating frequencies for tachometers, passive networks, or other ordinary integrating circuits.

The author thanks Messrs. E. Wade, C. B. Grady, M. W. Kalet, C. E. Holt, and many other colleagues at the W. L. Maxson Corp., for their co-operation.

Automatic Scale Makes Proportioning More Accurate

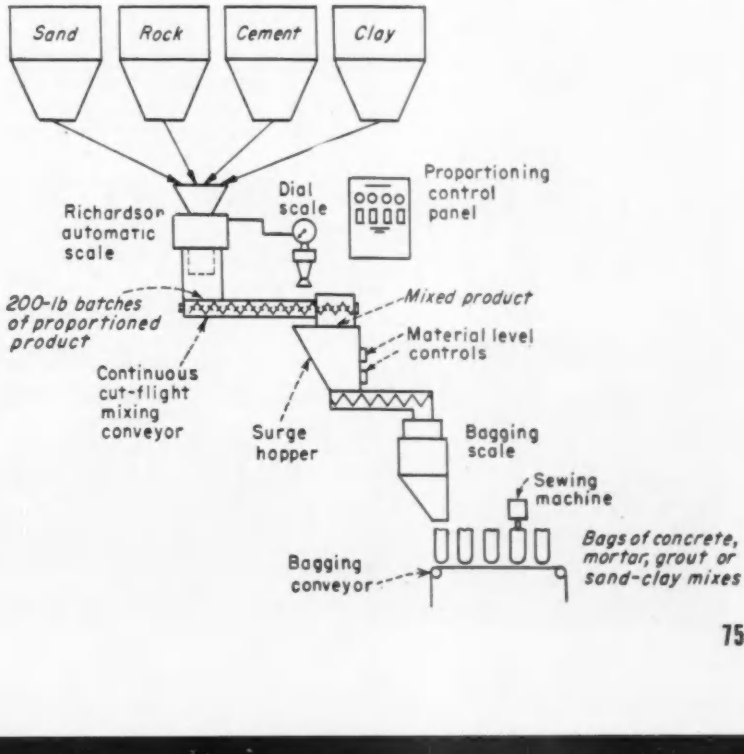
Pre-mixed packaged cement products, as well as other specialized aggregate mixtures, are proportioned automatically by a weighing system developed by the Richardson Scale Co. Replacing an older volumetric method, the batch gravimetric proportioning system is cutting costs and improving quality control for Dry Mix Products Co. in Roseville, Calif.

A single automatic scale proportions all mixes by cumulatively weighing individual ingredients. One man can turn out fifteen tons of mixed product per hour. The scale delivers a 200-lb batch every 24 sec to a cut-flight mixing conveyor.

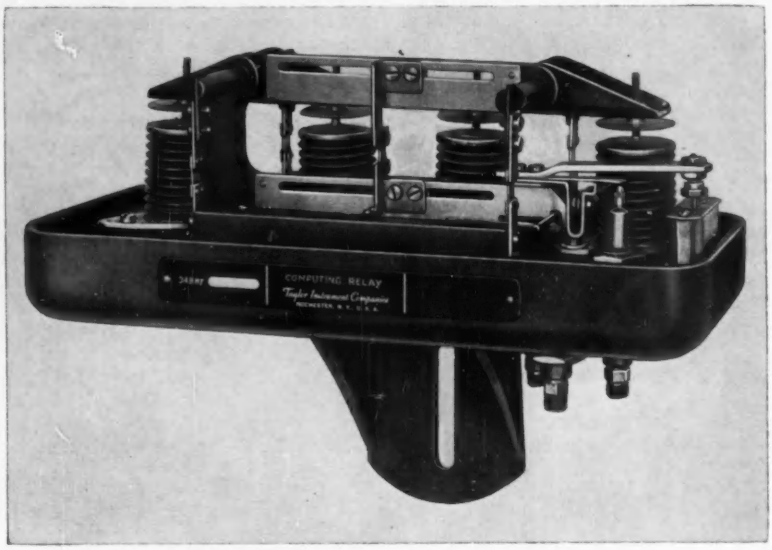
The control panel has four manually-set precision potentiometers—one for each ingredient. The feedback potentiometer is driven by the scale-dial indicator, and is connected in a bridge circuit opposite the first manually-set pot. As the scale is charged with sand from the first of the 30-ton bins, the bridge then balances. Balance in the bridge closes the gate on the first bin, substitutes the second manual pot for the first, and opens the gate on the second bin. The process is repeated for the third and fourth bins. Then the scale discharges its load to the mixing conveyor. After automatically checking the empty tare balance, the scale repeats the cycle.

The lower level control on the surge hopper locks the bagging scale unless sufficient material is present for an accurate weighing. The upper control interrupts the batching unit if the bagging operation lags.

The batch weighing system gives the highest possible accuracies. For example inaccuracies of batching scales are less than .1 per cent, weigh-feeders have accuracies in the order of 1 per cent, and volumetric systems are about 2 per cent.



NEW PRODUCTS



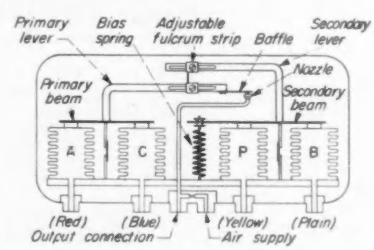
LISTING

PNEUMATIC COMPUTER adds, subtracts, averages, ratios, and can be rigged to control.

Pneumatic devices often tackle complex jobs with simplicity unmatched by other designs. Witness this ingenious computing relay just released by Taylor. Actually, it's a force-balance transmitter which has been set up to handle three independent input pressures and deliver a functional linear output with .005 per cent accuracy. And it does this by means of a few bellows, some levers, and a flapper-nozzle arrangement.

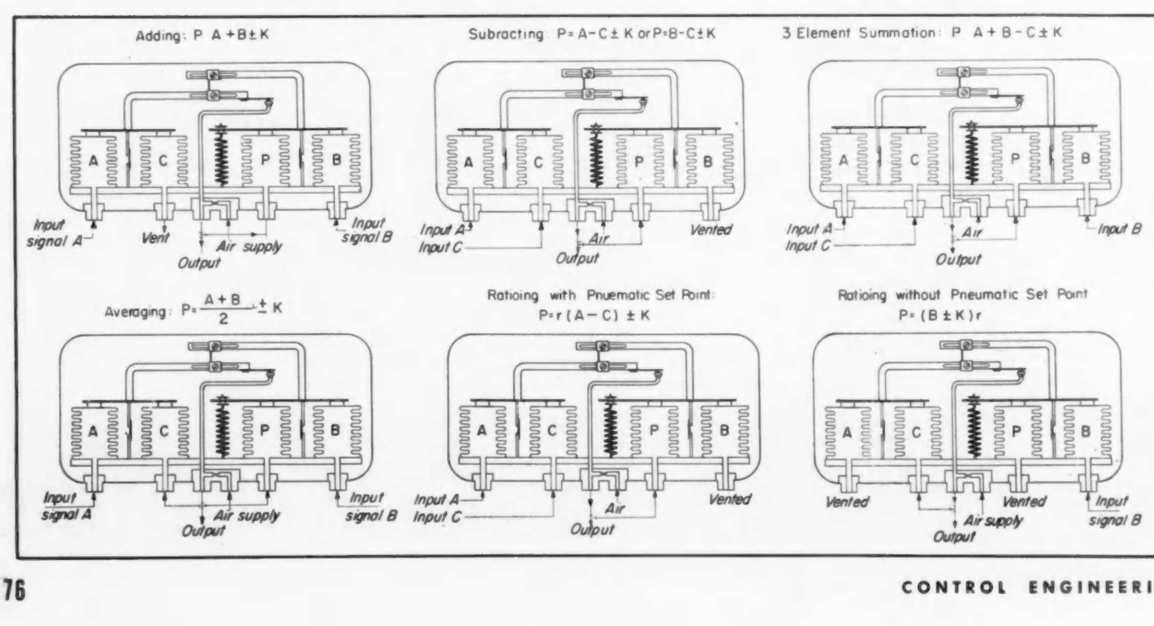
Input air pressures are routed to selected bellows, and resolution of their movement positions a moveable baffle relative to the fixed nozzle. The resulting change in nozzle back-pressure—or output signal—feeds back through the same lever system to keep the unit dynamically balanced.

Simple interchange of air connections sets this device up for various



How It Computes ↓

Its Innards ↑

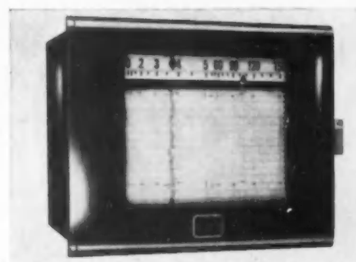


mathematical tasks (see diagrams) and also for direct use as a controller. In the latter function it can provide proportional response, automatic reset, and derivative response. With this versatility, its use seems clear in multi-variable process control as well as for a simple and effective pneumatic link in many types of computing systems. Also, by solving problems directly at site, the new relay can eliminate sizeable amounts of transmission tubing or wire. *Taylor Instrument Companies, Rochester, N. Y.*

Circle No. 1 on reply card

SPECIALIZED RECORDERS are appearing which simplify control intelligence and put chart readings in a more meaningful form for the operator. Four of these new functional instruments are described below.

CHARTS CURRENT AND VOLTAGE SIMULTANEOUSLY



Application

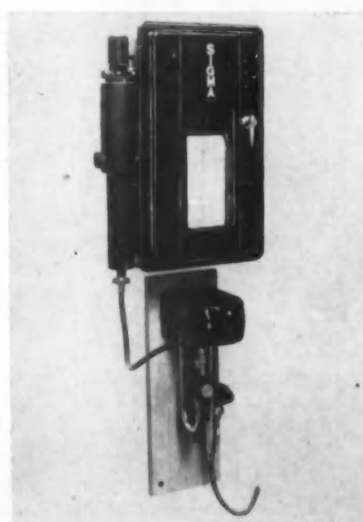
By incorporating a thermal voltage converter and a thermal current converter plus ac-dc transducers, this unit provides a one-chart, two-pen recording of amperes and volts. It can function in a voltage telemetering system without added internal or external equipment. *The Bristol Company, Waterbury 20, Conn.*

Characteristics

Accuracy.........Within 1 per cent
Sensitivity.........1/20th 1 per cent
Chart Speeds....$\frac{3}{4}$ in. per hr to 4 in. per sec
Pen Speed....Up to $1\frac{1}{2}$ sec full scale

Circle No. 2 on reply card

SHOWS HEAT FLOW FACTOR DIRECTLY



Application

An integral regulator in this British instruments sets it up to record continuously the heat-flow factor of a gas fuel instead of its BTU. The regulator controls gas flow to the instrument burner so that it is inversely proportional to the square of its specific gravity. Heat, measured by differential expansion of combustion tubes, thus shows up as heat flow factor on the chart. Ordinarily, to get this reading, both specific gravity and BTU would have to be checked and a formula calculated. The instrument has two parts, with flow regulator below recorder and combustion tubes mounted to left of instrument case.

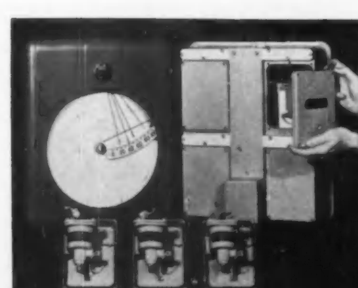
Cosa Corp., 405 Lexington Ave., New York 17, N. Y.

Characteristics

Chart Width.................4 in.
Chart Speed........$\frac{1}{2}$ or 1 in. per hr
Pressure Reducer..to 1 in. from 2-36 in. water
Governor Accuracy..about $\pm\frac{1}{4}$ per cent
Control Modes Available:
pneumatic, for mixing two gases
electric contacts, for high-low alarm

Circle No. 3 on reply card

HANDLES BOTH PNEUMATIC AND ELECTRIC SIGNALS



Application

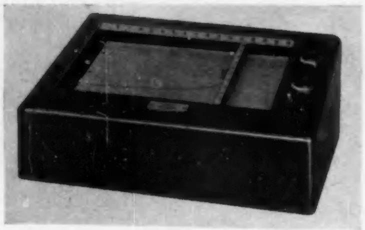
Here is a standard recorder that can provide a composite picture of as many as four variables in any process or electrical system. Because its plug-in receivers can handle either electric or pneumatic signals, it can group isolated information. It also can include integrators for flow measurements. *Bailey Meter Co., Cleveland, Ohio*

Characteristics

Case Size..14 x 17 in. panel mounted
Case Colors..green, buff, grey, black
Pen Type..fountain, with year's ink
Chart and Scale..12 in. chart with 6 in. "hot dog" indicating scale

Circle No. 4 on reply card

KING-SIZED FLAT-BED X-Y RECORDER



Application

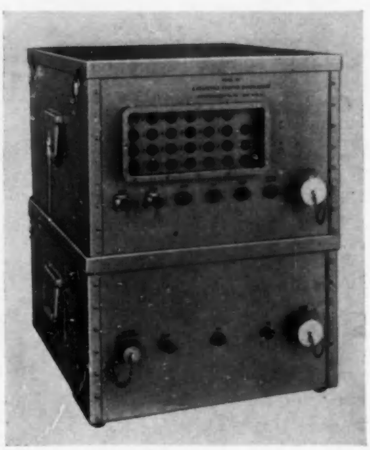
Two independent servo-actuated drives for X and Y axes trace a curve on regular 11 in.-by-16 in. graph paper in this flat-bed recorder, which permits on-chart notations during operation. Its versatility and attachments make it useful for data handling and computer applications. *F. L. Mosely Co., Pasadena 3, Calif.*

Characteristics

Speed. . . . . . 1 sec full scale both axes
Sensitivity . . ½ mv. per in. for both axes
Size. . . . . 23 x 16½ x 8½ in.
Weight . . . . 45 lb
Weight . . . . 45 lb

Circle No. 5 on reply card

ELECTRONIC COUNTING has cascaded into the control loop in only the past few years as a new means for totalizing pulse-type signals. Our new counting developments and their charcateristics are reported below.



RUGGED, BUT COUNTS SPLIT MICRO-SECONDS

Application

This ruggedly housed and designed split-microsecond counter offers laboratory dexterity under field conditions. In the picture the top cabinet holds the oscillator, electronic counter stages, and necessary control circuits; three separate power supplies are in the bottom cabinet. The unit is designed for field testing radar and sonar, but will probably be snatched up for industrial applications where conditions have been too tough for less rugged high-speed counters. *Potter Instrument Co., Inc., Great Neck, Long Island.*

Characteristics

Range (maximum interval. . . . . . 1 sec
Accuracy . . . . ±⅛ microsec
Oscillator. . . . . 8 megacycle, crystal controlled
Pulse frequency. . . . . ⅛ microsecond
Readout. . neon lamps indicate microseconds and eights of microseconds, recorder or printer also are available

Circle No. 6 on reply card

ELECTRONICS WORK AT TURTLE SPEED TOO

Application

Here is a low cost electronic counter "package" which is applied at visible speeds. In fact it simply adds a few items per second. It is set up primarily for counting production work in the plant, where accurate impulse signals from a compact photocell scanner can be sent to the centrally located indicator. Only one tube and a six digit totalizer are in its design. *Electronic Products Div., Post Machinery Co., Beverly, Mass.*

Characteristics

Pulse rate. . 2 to 3 per sec., but will handle bursts to 7 per sec.
Power. . . . . . . line voltages of 100-120
Distance. . . . . . counter can be 100 ft from pickup
Control. . on-off contacts to start or stop line-control solenoids and switches
Reset. . manual knob on face of unit

Circle No. 7 on reply card

TERNARY DESIGN, FRUGAL ON SPACE AND POWER

Application

Makers of this new plug-in counter claim that it will out perform more complex ring or binary units. In frequency division, for example, the device does the same job as a three-stage ring unit, or two binary stages with feedback. In addition to its function in a counter assembly, the ternary is suitable for gate control or division of frequencies by three. *The Walkirt Co., Inglewood 3, Calif.*

Characteristics

Frequency Range..........0 to 100
Required Pulse..between 60-150 amplitude, rise time from .5-1-5 microsec
Output Rise Time.......0.4 microsec
Power Consumption..7 ma at 250 vdc
Size......2 x 2 x 2 in., Weight 7½ oz.

Circle No. 8 on reply card

FREQUENCY COUNTER, COMPACT YET VERSATILE

Application

Simpler circuitry in this new frequency counter has significantly reduced its size and weight without sacrificing precision or functional use. Its time base is a 100-crystal-controlled oscillator with five divider stages. It can be supplied with tachometer pickup and photocell at extra cost, *The Detectron Corp., North Hollywood, Calif.*

Characteristics

Range..10 to 100,000 events per sec
Display Time..½ to 6 sec in one step
Size..........144 x 7½ x 13½ in deep
Weight ....28 lb
Gate Control..automatic and manual
Reset.........automatic and manual

Circle No. 9 on reply card

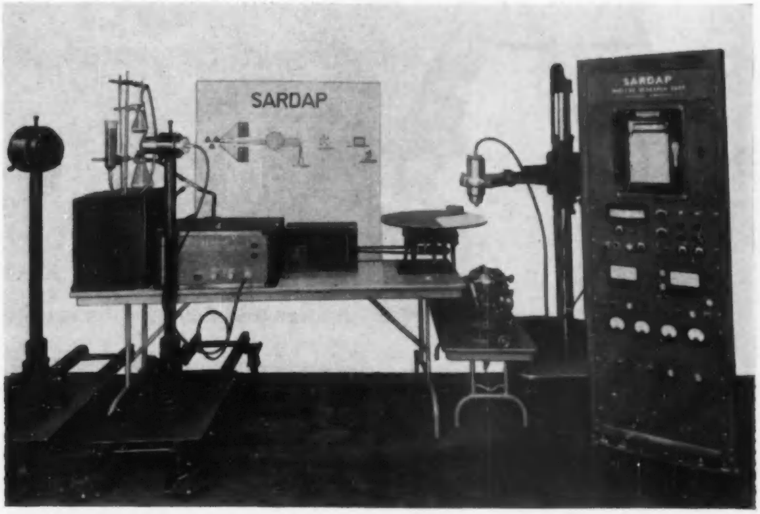
NEW WAYS TO MEASURE

GAMMA GAGING ferrets and describes flaws, tells liquid level too.

Inspection by gamma rays is a new measuring method with infinite possibilities. Witness the two new radiation devices in the picture above. The unit on the left is set up to measure and control liquid level inside a dense container with almost molecular accuracy. And on the right is an apparatus that will pick up and describe a metallic flaw as small as one-millionth cubic inch in volume.

Basically, the two units—the first in a series—operate this way. A gamma-ray source is beamed at the work, and the ray that pass through are picked up by a scintillation counter mounted on the other side of the work. An indicator or a chart shows intensity and pattern of penetrations.

Significantly, this flaw detector describes quantitatively what it spots. According to company engineers, it



Q

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By combining the abilities of your operators with semi-automatic equipment.

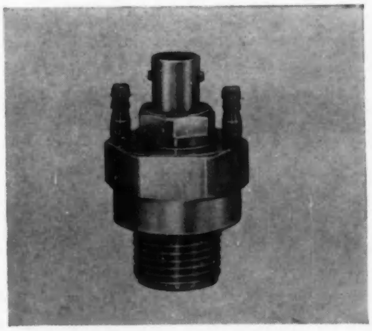
The Benson-Lehner Corporation will help you set up a system designed in building block form which will pay for itself in the shortest time by providing you with an increased flow of information, an accelerated test program, increased accuracy and reduced labor costs. The technical services of our staff are available to help you in the setting up of overall systems. For further information write to...

benson-lehner *corporation* Dept. A, 2340 Sawtelle Boulevard, West Los Angeles 64, California

will tell the user both the size and weight of the variation and will detect imperfections which would be overlooked by x-ray or mechanical inspection equipment currently available commercially.

Speculating on important applications of gamma-ray gaging, the engineers say that engine component failures and train accidents due to flaws in rails will be minimized through its use. *Nuclear Research Corp., Philadelphia.*

Circle No. 10 on reply card



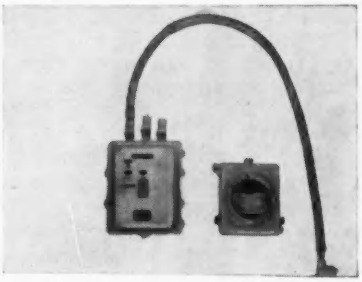
PRESSURE PICKUP with built-in cooling system.

A concentric water jacket keeps this capacitive-type pressure transducer cool enough to register accurately at temperatures up to 6,000 deg F. Other features:

Pressure Range......1 to 75,000 psi
Output.........15 with 25,000 load
Frequency Response....0-10,000 cps

Photocon Research Products, Pasadena 8, Calif.

Circle No. 11 on reply card



CAPACITANCE-TYPE level indicator explosion-proofed

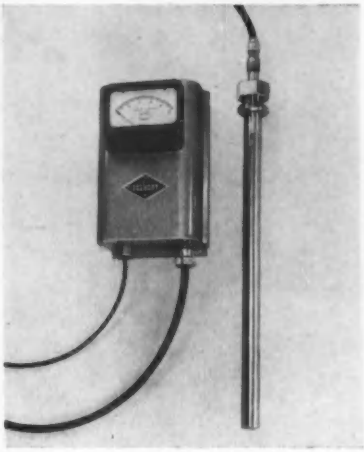
Specially-designed explosion-proof housings have been added to the probe, relay, and indicator of this capacitance level-control system. These meet requirements of the National Electric Code for flammable gases and vapors, including ethyl, ether, and gasoline products. The system can be located in dusts containing metal, coal products, or grain. *Fielden Instruments Div., Robertshaw-Fulton Controls Co., Philadelphia 33, Pa.*

Circle No. 12 on reply card

QUADRANT ORIFICE rules out viscosity errors.

Based on research done in Europe, this new orifice-type element will accurately measure the flow of fluids with varying viscosity. Secret of the device is its rounded upstream approach, which makes it insensitive to viscosity change at throat Reynolds numbers as low as 500. Conventional sharp-edge orifice plates are known to be unpredictable because of viscosity change when Reynolds number goes below 15,000. *Taylor Instrument Companies, Rochester 1, N. Y.*

Circle No. 13 on reply card



DUNKING PROBE continuously indicates product level

Material rising and falling along the length of this probe changes its capacitance proportionately. Thus, without floating or moving parts or contact-making electrodes, this new indicator is able to gage accurately the level in such products as milk, oils, refrigerants, and condensed gases.

The unit is set up to operate in a temperature range from −425 to 500 deg F and from high vacuum to 100,000 psi. Its probe can be as far as 1,000 ft from the indicator. Various probe lengths, materials, and designs are available. *Thermo Instruments Co., Belmont, Calif.*

Circle No. 14 on reply card

MACHINE CONTROL ADVANCES

ENGINE TESTER paces product under no-load conditions

A new engine can be hooked into this well-instrumented test stand and quickly put through its paces before being bolted down in a product. An integrated series of controls do this job in sequence and automatically.

Here is a typical series of its automatic, time-controlled operations:

1—Water pressure is increased to show block leaks.

2—Engine is continuously flushed with preheated oil.

3—Exhaust gas is analyzed after engine reaches a pre-set temperature.

4—Required oil inserted.

5—Water and oil or both are drained if engine is to be shipped empty.

During this sequence, indicator dials on the stand show rpm, intake-manifold vacuum, oil pressure, combustion efficiency, timing, and water temperature. Quick-clamping connectors are used for services, such as oil, water, gasoline, ignition, and exhaust. Also, the stand may include a starter, carburetor, fuel pump, ignition coil, and distributor cap. *Control Engineering Co., 8900 Alpine Ave., Detroit 4, Mich.*

Circle No. 15 on reply card

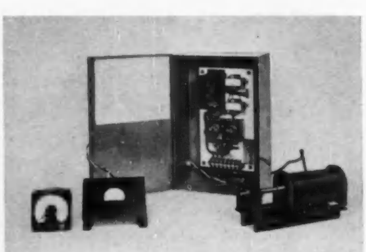
PRECISION GAGE measures, sorts 60 bearings per sec.

This new electromechanical gage measures both length and outside diameter of highly polished cylindrical roller bearings to within 0.0001 in. It then sorts each bearing into one of twelve size bins. It does all this at the rate of 60 bearings per sec.

Here's how it works. The bearings drop through a chute to reciprocating feeding fingers, which puts each into a slot in a wheel passing through the gaging station. Feeler contacts "ride" the bearing and send measurement to an implifier. A mechanical memory classifies the bearings and actuates the correct disposal chute for each as it leaves the wheel.

The instrument can gage range from 6,000 to 8,000 bearings per hour, and it is quickly adjustable to diameters and lengths ranging from $\frac{3}{16}$ to $\frac{5}{8}$ in. *Federal Products Corp., 1144 Eddy Street, Providence, R. I.*

Circle No. 16 on reply card



MOTION TRANSMITTER gets you back to start.

This position-measuring system tells the operator of a linear-motion machine how far it has moved. Using the dial, he then can return his machine to the original position with less than one per cent error. It transmits total motion ranging from $\frac{3}{8}$ to 3 in.

Components of the system are shown in the picture. A rod that indicates machine position influences the output of transmitting pot (right). This signal drives the position indicator (left) which is mounted at the operator's station. The control panel (center) insures a stable voltage supply.

An important use for the indicator is setting pass positions of rollers in steel mills. It should be useful in any machine or system operation where work is moved in linearly and production is handled in units. *Control Products Co., Inc., Oakdale, Pa.*

Circle No. 17 on reply card

UNUSUAL INSTRUMENTS

STREAK CAMERA plots position vs. time.

Such mercurial happenings as spark discharge, explosion, and shock wave can be plotted by this synchronized streak camera, provided they are controllable with respect to time co-ordination. The camera records them on a 4x10 in. film, with vertical axis representing space and horizontal axis time.

Elements of the system are seen in the picture. Image of the event enters camera viewing slit (left) and is swept across the film by a 50,000 rpm rotating mirror. This equals a writing rate of 5.46 mm per microsec.

At the right is the control console which remotely operates and monitors the event under study. It synchronizes the camera with the event by a pulse-delay action with less than 0.2 per cent error in speed and within a maximum of 0.6 microsec variation. Output pulses can also be used as an oscilloscope sweep-trigger to make transient-time measurements of the event.

Incidentally, the large cabinet under the camera contains a vacuum pump—needed because of the high mirror speed—and electric drive for the mirror. *Beckman and Whitley, Inc., San Carlos, Calif.*

Circle No. 18 on reply card

TELEMETERING System pulses proportional signals.

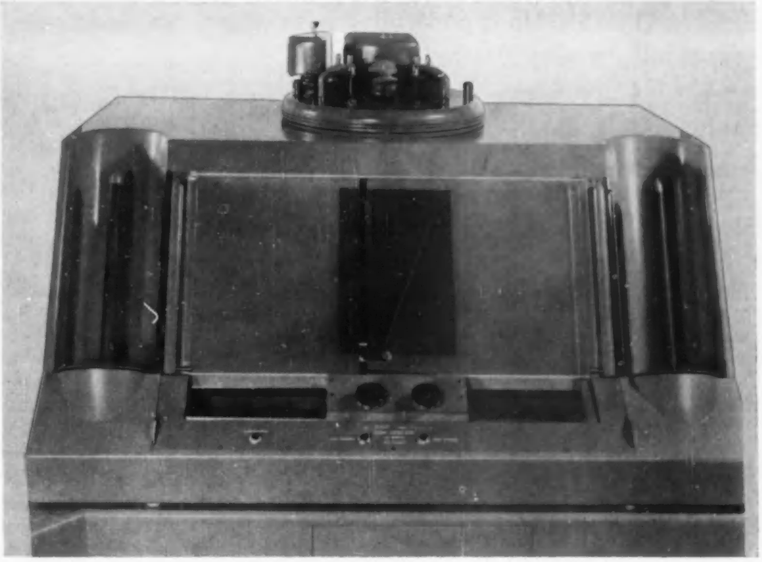
Here is an ingenious system for telemetering accurate measurements over long distances. It employs a periodic (12-sec) pulse transmission. The time duration of this pulse is proportional to the variable being

measured. The pulse goes by wire, radio link, or microwave channel to a central receiver. Here the duration is compared to that of the previous pulse signal, and the recording mechanism is rebalanced to new reading.

The signal level may vary widely without affecting operation or accuracy. This is so because the telemetered information is a function of pulse duration rather than magnitude.

Actually, the transmission may consist of an ac or dc signal over a pair of leased lines or private wires, or a frequency signal over radio link or microwave system. For dc transmissions a power pack converts an ac input to suitable dc signal. The maker does not furnish the transmission medium. *The Foxboro Company, Foxboro, Mass.*

Circle No. 19 on reply card



SCOPE AND FILM READER serves up data for computer.

Handsomely styled, this electronic data-reduction machine mechanically scans oscillographic and film records. With it the operator converts information to rectangular or curvilinear coordinates, which can be digitalized and fed into a computer and readout system.

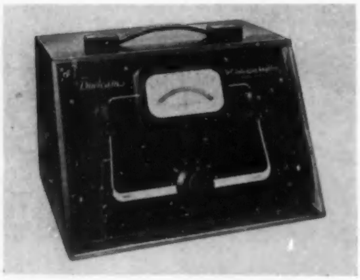
Prime use for the reader is an analysis of complex performance data. In addition to reading oscillographs and large film records, the machine has a projector and mechanized movement for enlarging and analyzing 16 and 35 mm microfilms. *Benson-Lehner Corp., W. Los Angeles 64, Calif.*

Circle No. 21 on reply card

FOOT CONTROLS computer for cost accounting.

The desk-sized mechanical analog computer shown is much easier to use now that it has a foot-pedal control. It totals flow records on 3 in. strip charts from miniature graphic panel recorders. It does this by direct square-root extraction. The foot pedal slows chart movement through the computer during any period of unusual record or upset. When the flow record is smooth, however, the chart will zip through at about 2 ft (24 hours of data) in 15 sec. *Librascope, Inc., Glendale, Calif.*

Circle No. 20 on reply card



MAGNETIC converter boosts amplifier performance.

Use of a second-harmonic magnetic converter rather than vibrator-type gives greater stability and reliability to this dc amplifier, claims its maker. Its mirrow-scale, zero-center meter registers magnitude and polarity of input dc signal. The instrument is completely self-contained.

This is a broad measuring instrument and can be paired with practically any dc signal-producing sensing element, such as a thermocouple or strain gauge. It can also be a drive stage for any motor and galvanometer recorders. *Doelcam Corporation, Soldiers Field R., Boston 35, Mass.*

Characteristics

Stability . . less than 10 microvolts long term drift
Dynamic Response . . flat from 0 to more than 20 cps
Sensitivity . . will measure signals down to 2 x 10-15 watt
Input Impedance . . . 1 megohm per V
Output . . for over 1500 ohms—plus or minus 15 V. max. for under 1500 ohms—plus or minus 10 ma max
Ranges . . . 1, 3, 30, 100 mv full scale

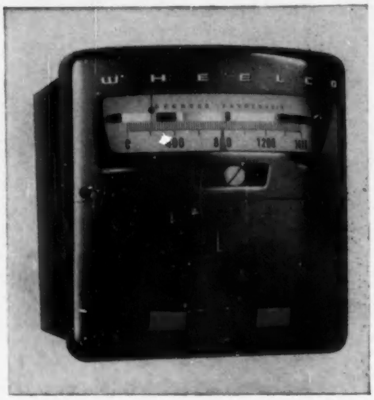
Circle No. 22 on reply card

FEEDBACK FANCY

Needed: A jostling servo to wake the nodding driver.
Suggested: Either a heavy head or a flabby hand could trigger this system. When the driver's head tilts or his hand slips from the wheel, the servo could nudge him in the ribs.

NEW PRODUCTS

WHEELCO DESIGNS a controller with many points in mind —especially maintenance.



These were the objectives facing Wheelco engineers before they designed the company's new line of millivoltmeter controllers. They wanted:

- a distinct and tasteful product.
- wide control flexibility.
- very easy scale reading.
- universal mounting.
- low-cost manufacture.
- and—above all—a unit that would be easy to service on the job.

Here are some of the problems they solved in meeting these objectives.

For service and flexibility, they decided to make the whole instrument from plug-in parts. To do this they had to 1) come up with a new housing, 2) modify their basic millivoltmeter, and 3) design a universal controller chassis.

The housing problem was solved with a two-section case. This permits replacing the control without disturbing the meter, and vice-versa.

Redesigning the meter was more complex. It had to be plug-in and self-contained, yet able to meet industry standards with a sensitivity of 0.1 per cent of scale span. To do this they took a basic D'Arsonval movement and modified its mounting bracket with a plug-in. The pick-up coils were then redesigned for use on any chassis. Next, the zero adjustment and control-point setting were made integral with the mounting. And finally the negative temperature coefficient resistor was modified to produce greater instrument stability.

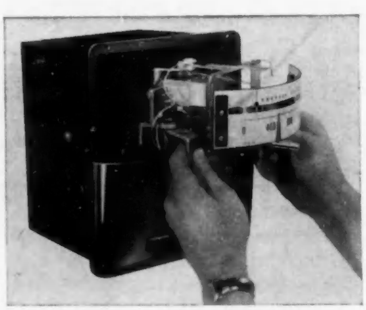
To get interchangeable control the designers selected a standard, common-denominator #12AU7 tube and designed the control chassis around it. All control modes thus employ an oscillating amplifying circuit, with any necessary additional relays, and control devices mounted neatly on the standard chassis base.

A curved viewing window makes the controller easy to read. A compact 9 in. sq case with a shallow enough chassis cavity to permit necessary wiring clearances makes universal mounting possible. Total weight of the unit turned out to be only 16½ pounds.

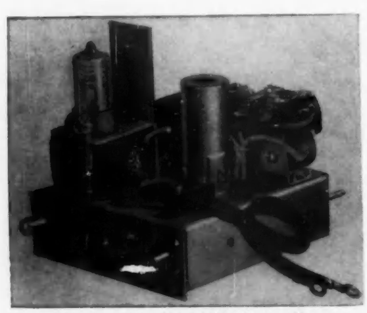
A completely die-cast house, with display face overlayed by a phenolic cover made it inexpensive to manufacture. No machining operations were involved other than tapping and drilling the necessary holes for terminal blocks, cover sections, etc.

Applications for this attractive, low-cost, and serviceable unit are primarily in heat treating, where temperatures are controlled between 400 and 3000 deg F. *Wheelco Instruments Div., The Barber Coleman Co., Rockford, Ill.*

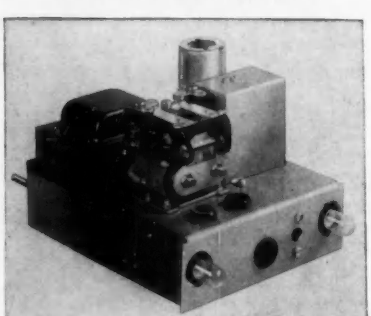
Circle No. 23 on reply card



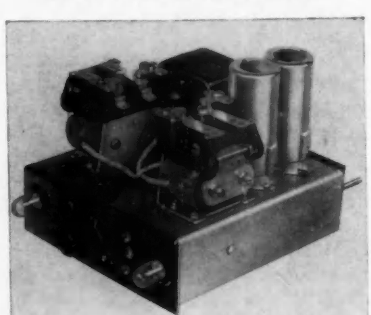
Galvanometer Measuring System



Two-Position (On-Off) Controller

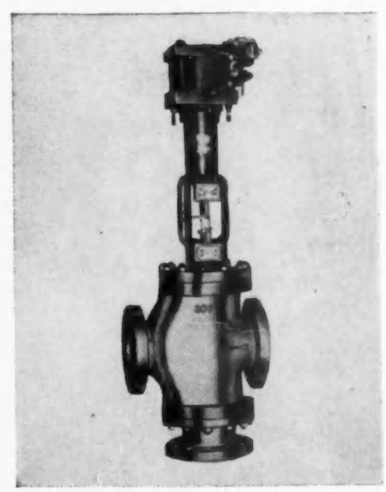


Time Proportioning Controller



Multi-Position Controller

CONTROL VALVES



CYLINDER-OPERATED valve moves fast up or down.

It takes less than 0.5 sec to tightly shut off this three-way valve using less than 100 psi thrust pressure. On return stroke it does just as well, although a spring rather than cylinder supplies return power. However, spring return can make the valve fail-safe.

Power cylinder on this valve can be operated by gas or fluid and may be equipped with a positioner for throttling service. The body is supplied from ½ to 10 in. in any machineable metal. Stuffing box can employ either Teflon or greased lubricant.

This new valve appears to be well

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4	11	18	25	32	39	46	53	60	67	74	81	88	95
5	12	19	26	33	40	47	54	61	68	75	82	89	96
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Company..

(51) AIRBORNE INSTRUMENTS. G. M. Giannini & Co., Inc., Catalog 10M-7-54, 52 pp. Describes electrical and mechanical characteristics of line of aircraft instruments. Items covered include accelerometers, pressure instruments, and machmeters, gyros, and vanes and probes. Specifications are detailed and complete.

(52) INFRA-RED SPECTROMETER. The Perkin-Elmer Corp., Bulletin, 6 pp. Covers construction details, performance and application data on the Model 112 single beam, double pass, recording infrared spectrometer. Includes spectral drawings to illustrate the flexibility of this new model.

(53) CYCLE CONTROLLER. The Sinclair-Collins Valve Co., Bulletin, 23 pp. Information on a timer to control complex cycles used on automatically controlled hydraulic presses. Electrically driven, cam-actuated unit has choice of electrical or pneumatic output. Specifications and illustrations of available gear boxes and cam arrangements are given.

(54) ELECTRONIC COMPONENTS. E. F. Johnson Co., Catalog 975, 20 pp. Includes details on a line of electronic products. Electrical and mechanical specifications are given. Products covered are capacitors, inductors, sockets, insulators, plugs, jacks, knobs, dials, and pilot lights.

(55) TEMPERATURE DETECTOR. Thomas A. Edison, Inc., Instrument News 9, 2 pp. Discusses an overtemperature-alarm system for monitoring aircraft equipment. Details of development, performance, and application are given.

(56) SENSITIVE RELAYS. Kurman Electric Co., Inc., Catalog GS, 17 pp. Gives technical details of a line of sensitive relays for control-system application. Relay types include powerful sensitive, midget sensitive, medium power, telephone, miniature telephone, time delay, latching, and polar.

(57) ACTUATOR MOTOR. Dalmotor Co., Form SR-43, 2 pp. Describes a series-wound miniature clutch-brake motor for use in low- or high-speed, linear- or rotary-actuator applications. Outline dimensions and electrical specifications including performance curves are given.

(58) THERMAL CONTROLS. Fenwal Inc., Catalog 400, 50 pp. Complete technical information on a line of Thermoswitch thermostats and temperature control systems. Feature of booklet is comprehensive information on the proper application of these components and systems. Well illustrated.

(59) INDUSTRIAL INSTRUMENTATION. Consolidated Engineering Corp., Brochure, 21 pp. Briefly describes a line of industrial instruments and includes general and specific application information. Actual case history discussions of uses of such instruments as mass spectrometers, recording oscillographs, and digital data processing systems are included.

(60) MOTORS AND BLOWERS. Mission-Western Engineers, Inc., Bulletin 254. Describes approximately 50 basic types of miniature and sub-miniature electric motors, blowers, and fans.

(61) PRECISION POTENTIOMETERS. Helipot Corp., Technical Paper 341, 8 pp. Technical presentation covering the characteristics of precision-servo computer potentiometers. Discusses potentiometer linearity and trends in the development of these devices.

(62) HIGH-PRESSURE VALVES. High Pressure Equipment Co., Bulletin 654, 2 pp. Describes a line of 30,000 psi valves. Items include a two- and three-way angle and straight valves, with color-coded handles.

(63) WORM GEARING. Vard Inc., Catalog 1002-2, 19 pp. Useful engineering data on the design of worm gearing. Includes list of required design data, detailed design procedure, and material and lubrication considerations. Sample problem covers complete design sequence.

(64) GERMANIUM DIODES. Hughes Aircraft Co., Bulletin SP2A-OOM-GP, 7 pp. Gives basic information and detailed specifications on a line of germanium diodes. Units are listed for both military and commercial use. Application hints and characteristic curves are featured.

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3	10	17	24	31	38	45	52	59	66	73	80	87	94
4	11	18	25	32	39	46	53	60	67	74	81	88	95
5	12	19	26	33	40	47	54	61	68	75	82	89	96
6	13	20	27	34	41	48	55	62	69	76	83	90	97
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(65) FLOW TUBE. Builders-Providence, Inc., Bulletin 115-L3, 16 pp. Describes new short differential-producing metering device. Includes information on recovery characteristics, accuracy, applications, range, flow formula, laying length, and working pressure. Tables and graphs aid in flow tube selection.
(66) GEARHEAD MOTORS. Merkle-Korff Gear Co., Circular SG15-4, 4 pp. Covers mechanical and electrical specifications for a line of small gearhead motors for use in industrial control apparatus. Suggested applications include remote positioning, measuring, indicating, and adjusting. Speeds range from 700 rpm down to one revolution in five minutes.
(67) ELECTRONIC DATA PROCESSING. Remington Rand Inc., Brochure EL 187, 9 pp. Discusses the card-to-magnetic tape converter used with the Univac system. Includes description and detailed directions for setting up the unit.
(68) SOLENOID VALVES. Automatic Switch Co., Bulletin 8210A, 4 pp. Technical data on a line of two-way solenoid valves for controlling flow of air, gas, water, light oil, and other noncorrosive fluids. Flow curves, dimensions, and electrical specifications are given.
(69) INDICATING AMPLIFIER. Doelcam Corp., Bulletin 1A, 2 pp. Describes a completely self-contained dc indicating amplifier for the amplification and measurement of small voltages and currents. Performance curves, electrical specifications, and a typical industrial application are shown.
(70) PRECISION CAMS. Ford Instrument Co., Division of the Sperry Corp., Bulletin, 4 pp. Well illustrated booklet describes a wide variety of types and sizes of cams. Useful as accurate mechanical memories for analog computers and other systems. Cam groupings include three-dimensional (two inputs) and single-input cams.
(71) SILVER-ZINC BATTERIES. American Machine and Foundry Co., Brochure, 6 pp. Information on a line of silver-zinc batteries ranging in size from those used in small electronic instruments to those used in jet engines. Technical data charts and specifications are included.
(72) INSTRUMENT GEARS. Micron Gear Mfg. Co. Catalog illustrates type of work done by company in the field of precision instrument gears. Applications include aircraft actuators, business machines, computing machines, gun sights, fire controls, servomechanisms, and synchro generators.
(73) INDUSTRIAL PERISCOPES. Kollmorgen Optical Corp., Bulletin 301, 4 pp. Describes industrial periscopes for remote viewing. Construction details, how to plan for a periscope, and data required when ordering unit are covered.
(74) X-Y RECORDER. F. L. Moseley Co., Bulletin, 8 pp. Describes a general purpose portable two-axis graphic recorder, and a point plotter and curve follower for use with recorder. Point plotter will plot data from digital sources such as a keyboard or tape. Curve follower will read out drawn curves in analog or digital form.
(75) GAS ANALYZER. Taller & Cooper, Inc. Bulletin 501, 4 pp. Information on a sensitive gas analyzer for detecting hazardous gases in low concentration. Can be used for laboratory gas analysis or continuous monitoring of industrial areas. Booklet includes operating principles and list of typical gases.
(76) TEMPERATURE-MONITORING SYSTEM. Thermo Electric Co., Inc., Bulletin 70, 8 pp. Describes 20-point-per-minute monitoring system available in standard units of 10, 25, 50, and 100 points. Mechanical and electrical specifications and various ways to combine components are discussed.
(77) TIME DELAY RELAYS. A. W. Haydon Co., Bulletin AWH RC200, 2 pp. Describes cycling time, timing accuracy, characteristics, and determination of timing tolerances for a line of miniature hermetically-sealed repeat-cycle timers.
(78) MINIATURE CONNECTORS. DeJUR Amsco Corp. Catalog sheet describes two series of miniature connectors. Rectangular units (G-20) are available with 2, 3, and 4 contacts; hexagonal units (HC20) with 4, 5, 7, 9, and 10 contacts.
(79) MOTOR CONTROL. Furnas Electric Co., Catalog 101, 140 pp. Covers engineering and design data on a line of electric-motor controls. Among items included are magnetic starters and contactors, control panels, drum-controllers, and master, foot, and pressure switches.
(80) METALLIC FILM POTS. Fairchild Camera and Instrument Corp., Potentiometer Div. Technical paper covering the general design and performance characteristics of film type potentiometers.
(81) FLEXIBLE SHAFT COUPLINGS. Kupfrian Mfg. Co., Catalog 5494, 16 pp. Information relating to the design and use of flexible shafts and couplings. Included is a table listing the physical properties of flexible shafts and shaft casings, and detailed illustrations of shaft coupling, assemblies, and components.
(82) BORON-CARBON RESISTORS. Shallcross Mfg. Co., Bulletin 1-33. Detailed performance characteristics including charts, tables and dimensions for a line of boron-carbon resistors. Also included is a comparison of boron-carbon and straight deposited-carbon resistors.
(83) PAPER ELECTROPHORESIS. Specialized Instruments Corp., Form 4R-554, 4 pp. Describes a new paper electrophoresis system including all instrumentation for a standardized operating procedure. System permits reproducible separation of components and measurement of their concentrations.
(84) VIBRATION AND SHOCK MOUNT. Robinson Aviation Inc., Specification Sheet 1090, 2 pp. Describes center-of-gravity type mounting system for electronic equipment. Dimensional and performance characteristics are included.

suited for emergency diversion service as well as for positively controlled fluid proportioning. *Kieley & Mueller, Inc., Middletown, N. Y.*

Circle No. 24 on reply card

BURNER VALVE works electro-hydraulically

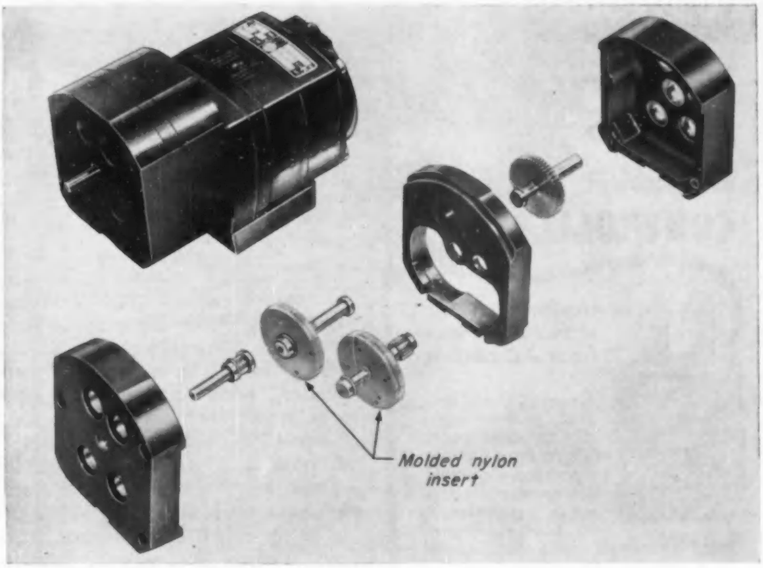
Designed to cope with high gas pressures in on-off control and safety shutdown of industrial burners, this new valve series has a special electro-hydraulic pump as actuator.

Characteristics

Pressure range.........5 to 35 psi
Opening time...can be varied from 6 to 28 sec
Shutoff time....1 sec in all models
Valve sizes........from 1 to 6 in.
Body..cast iron with aluminum trim

General Controls Co., Glendale, Calif.

Circle No. 25 on reply card



GEAR BACKLASH curbed by sandwiched nylon.

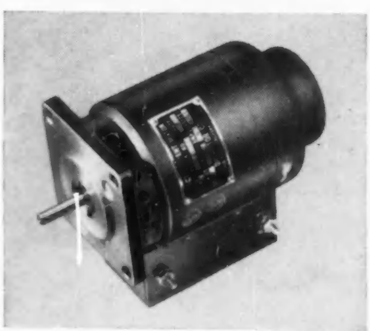
A neat design trick of enclosing a wafer of nylon to form the central part of gear teeth appears to be a good answer to backlash problems in precision-servo gear trains. Apparently the nylon expands slightly after the teeth are cut—just enough to reduce backlash without adding to torque. Typical characteristics of a specially built gear box with this design are:

Ratio....................90 to 1
Output Torque...........30 oz in
Friction Torque........0.375 oz in
Backlash ....0.02 deg

Dexter Machine Products Co., Chelsea, Mich.

Circle No. 27 on reply card

SERVO COMPONENTS



CONSTANT SPEED cancels static with built-in filter.

This $\frac{1}{8}$ hp motor is designed primarily to spin a radar antenna, but can be put to work in many airborne services requiring constantly governed speed. One of its radio-frequency propensities is a special interference filter mounted on the motor frame.

Characteristics

Speed....7,100 rpm ±1.0 per cent
Voltage ....24-30 vdc
Load Variations......±30 percent
Torque ....$9\frac{3}{8}$ lb-in
Weight ....5.5 lb

Dalmotor Co., Santa Clara, Calif.

Circle No. 26 on reply card

RATE GENERATOR translates speed to ac voltage.

This "dragcup tachometer" functions as a two-phase induction generator in linear conversion of rotational motion into voltage. Its cylindrical dragcup rotates in the air gap between stator and core. When one stator phase is excited by a constant-voltage source, output from the other stator phase has an amplitude proportional to dragcup speed and a frequency the same as the excitation voltage.

Although useful in direct speed measurements and in computing where rate is a direct function, the tachometer is designed chiefly to be a velocity feedback element in servo systems. Incidentally, as the picture shows, the generator (foreground) can be supplied packaged with any of the maker's 10 servo motors.

Characteristics

Accuracy....0.1 per cent deviation from linearity at 1800 rpm
Output........6.8 v per 1,000 rpm
Weight ....1 lb

Ford Instrument Co., Long Island City 1, N. Y.

Circle No. 28 on reply card

FEEDBACK FACT

Posed: Some way to eliminate tedium and error in blood-cell counting.
Solved: Jarrell-Ash offers an impulse scanner that will instantaneously compute the corpuscle count of even a spinach eater.

WHAT'S NEW: BOOKS

Sonic Roundup

ELECTROACOUSTICS. *Frederick V. Hunt, Professor of Applied Physics, Harvard University. 6 by 9 in., 260 pp. Published by Harvard University Press, Cambridge, Mass. and John Wiley & Sons, Inc., 440 4th Ave., N.Y. 16, N. Y. $6.00*

This book presents a unified basis for the analysis of all electroacoustical transducers. A modified formulation of the electromagnetic relations, involving the introduction of a "space operator," allows all transducer types to be represented by the same form of equivalent circuit. This makes it advisable to use electric-impedance analysis for the study of transducer performance. These methods, like the use of equivalent circuits, were introduced earlier, but were further developed during the war. Research reports on the work at the Harvard Underwater Sound Laboratory under NDRC auspices during the 1941-45 period have not been generally available, and the only summary had limited distribution.

The generic types of electromechanical coupling include two that use a magnetic field and one that uses an electric field. These are exemplified by movable conductors in a fixed magnetic field, by fixed conductors linking a variable magnetic field, and by movable conductors bearing fixed or variable electric charges.

The first chapter of this book is a 90-page account of the historical origins of electromechanical transducers in the basic sciences and their allied arts. Some of the notes, based on original sources and personal interviews, deal with the origins of echo ranging, the crystal oscillator, electrostatic transducers, and the evolution of the dynamic loudspeaker.

Nuclear Reactor Facts

NUCLEAR REACTORS FOR INDUSTRY AND UNIVERSITIES. *Edited by Ernest H. Wakefield. 5¼ by 8¼ in., 94 pp. Published by Instruments Publishing Company, Pittsburgh 12, Penna.*

The stated purpose of this book is to help universities and industries make decisions about the installation of reactors. Nationally known authorities have written the chapters.

Certain chapters should be especially interesting to control engineers. For example, besides the description and classification of reactor types, there are chapters on radioactivity measurement, reactor control, and instrumentation for experiments.

The chapter on radioactivity measurement describes the uses of photographic film, conduction detectors, chemical integrating indicators, cloud chambers, ion chambers, proportional counters, Geiger-Mueller counters, and scintillation counters.

Reactor-control equipment described includes the logarithmic count-rate meter, the micromicroammeter channel, the log N channel, and the safety channel.

Instrumentation described includes A-1 linear amplifiers, binary and decade sealers, counting rate meters, and the scintillation spectrometer.

Chem Engineering Complete

CHEMICAL ENGINEERING, VOL. I. *J. M. Coulson and J. F. Richardson, Imperial College of Science and Technology, London. 6 by 9 in., 370 pp. Published in U.S.A. by McGraw-Hill Book Co., Inc., 330 W. 42nd St., N. Y. 36, N. Y. Published in Great Britain by Pergamon Press Ltd., Maxwell House, Marylebone Road, London N.W. 1. $7.50.*

This new text treats the various processes of the chemical field as a series of unit operations. Research and development have expanded the subject during the past twenty years. But despite the many books specializing on certain sections, such as distillation and heat transfer, there are few general texts.

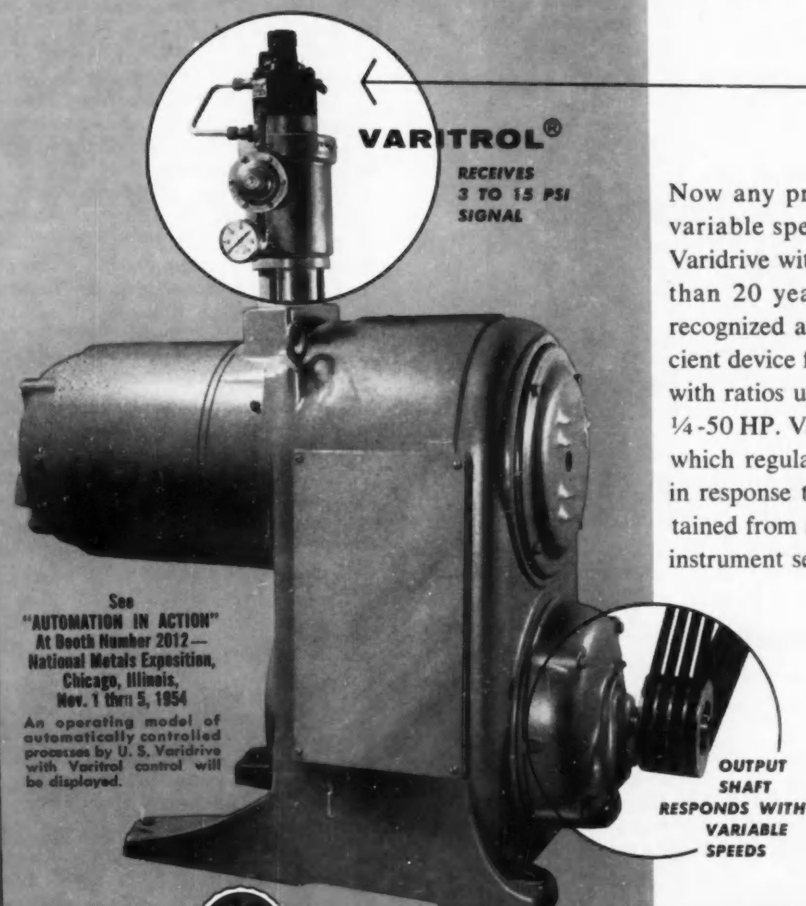
Volume I is concerned with the

YHW TON ETUNIMS?

We will pay $3 (that's THREE DOLLARS) to anyone who can top this anecdote about the evolution of the control engineering profession's terminology:

Reset action (integration action with respect to time) was conceived, and its parents were seeking a unit of measurement. Should the unit be minutes per repeat, repeats per minute—or what? A godparent with a flare for words came up with what we think is an apt coinage: ETUNIMS—the plural of "minute" spelled backwards. Lovely but lost; perhaps it wasn't complicated enough.

AUTOMATIC CONTROL OF VARIABLE SPEEDS



Now any process requiring automatic variable speeds can be driven by U. S. Varidrive with Varitrol control. For more than 20 years the Varidrive has been recognized as the most compact and efficient device for obtaining variable speeds, with ratios up to 10:1 and capacity from ¼-50 HP. Varitrol is a new control device which regulates the speed of a Varidrive in response to a signal. The signal is obtained from a standard type of pneumatic instrument sensitive to such variables as:

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Humidity	Weight
Pressure	Tension
Speed	Position

Many firms are increasing productivity with Varitrol control. Quality of product is improved, human effort is reduced. Lower costs result in better salability of your products.

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An operating model of automatically controlled processes by U. S. Varidrive with Varitrol control will be displayed.

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physical basis for the important chemical engineering operations, and is divided into four sections: fluid flow, heat transfer, mass transfer, and humidification. Volume II will apply these theoretical foundations in the design of distillation columns, filters, crystallizers, evaporators, etc. Mathematical treatment is rigorous and assumes that the reader can handle partial differential equations. Problems, on the other hand, are given fairly detailed treatment, however.

Chapter heads include: Units and Dimensions; Energy Relationships; Friction in Pipes and Channels; Flow Measurement; Pumps for Chemical Works; Heat Transfer; Mass Transfer; Momentum, Heat and Mass Transfer; The Boundary Layer; Humidification and Water Cooling.

The chapters on flow measurement and pumps are particularly interesting to the control engineer, since normal engineering texts do not cover the problems that occur in the chemical and petroleum industries.

The chapter on heat transfer contains an account of the generally accepted techniques for the calculation of film transfer coefficients for a wide range of conditions, and includes a section on the general construction of tubular exchangers. Another chapter explains how the boundary layer is developed over plane surfaces and in pipes, since it is so important in controlling heat and mass transfer.

How to Solve Problems

ENGINEERING ANALYSIS. *D. W. Ver Planck and B. R. Teare, Jr., Carnegie Institute of Technology. 6 by 9 in., 344 pp. Published in U.S.A. by John Wiley & Sons, Inc., 440 4th Ave., N. Y. 16, N. Y. Published in Great Britain by Chapman & Hall, Ltd., London.* $6.00

The professional engineer solves a problem in the following stages: 1) defining the specific problem he will attempt to solve; 2) planning his attack, making such simplifications as may seem necessary, and deciding on what principle to base his attack; 3) executing his plan until he reaches a decision or result; 4) checking his work thoroughly; and 5) taking stock to see what he has learned about the given situation as a whole, and what may be of future use; that is, learning and generalizing.

This book gives special emphasis to stages 1, 2, 4, and 5, the first two being, in essence, the translation of the engineering situation into mathematical language, the last two, what

is done after the mathematical crank has been turned and a result obtained.

The book treats a number of subjects needed by engineers from the viewpoint of use and true understanding. The topics include material from dynamics of translation and rotation, electric circuits, heat transfer, solution of linear differential equations with constant coefficients, uses of power series, integration by graphical and numerical methods and the evaluation of indeterminate forms.

Analog Computation, A to Z

ANALOG METHODS IN COMPUTATION AND SIMULATION. Walter W. Soroka, *Professor of Engineering Design, University of California*, 6 by 9 in., 390 pp. *Published by* McGraw-Hill Book Co., 330 W. 42nd St., N. Y. 36, N. Y. $7.50.

This is the first book that organizes and classifies all of the important methods of analog computation. It describes mechanical, electro-mechanical, electrical, and electronic analog components that perform basic mathematical operations. These components are then combined to solve the various kinds of engineering equations. The treatment is fundamental and develops the theoretical basis for each approach. A thorough bibliography references important papers on analog computations.

The scope of the book is indicated by a listing of chapter heads, which are: Mechanical Computing Elements; Electromechanical, Electrical, and Electronic Computing Elements; Machines for Simultaneous Linear Algebraic Equations; Analog Solution of Nonlinear Algebraic Equations; The Mechanical Differential Analyzer; Electronic Analog Computers (Electronic Differential Analyzers); Dynamical Analogies; Equivalent Circuits for Ordinary and Partial Differential Equations in Finite Differences; Membrane and Conducting-Sheet Analogies.

About three-fourths of the book deals with differential equations and the various components and methods available for their solution by construction of analogs. Complexity ranges from the simple homogenous linear equation to the lattice- and membrane-analogies for partial equations. The chapter on dynamical analogies is notably extensive, and should help engineers and teachers understand the various physical systems and their similarities. This book will probably become a standard reference for the control engineer.

DAVE BOYD (cont. from page 11)

of what an analog computer should do in a petroleum refinery. The notions were sound and concrete, for Dave was the man largely responsible for the first refinery graphic panel, installed at the Rock Island refinery in 1949.

UOP officials were so impressed with Albert that they invited Dave to move his brainchild to the company's Administrative and Engineering Building in Des Plaines, Ill. There the computer keeps busy. One of its first assignments was to make performance studies of the Rock Island electronic control system.

Much of the credit for Dave's success belongs to his wife Louise. After he suffered a devastating attack of polio seven years ago, while at Oak Ridge, she kept up his spirits. He confounded the doctors by recovering. Says Dave: "They forgot to tell me I would never walk again."

How does Louise feel about the constant turmoil in her home? Dave grins and comments: "She's a broad-minded woman. I think she summed it up very well when she said, 'Just remember, many husbands spend all day Sunday washing the family car.'"

FEEDBACK FACT

Posed: Director-to-thespian telemetering in movie mob scenes.

Solved: Warner Bros. has just patented (U. S. No. 2,685,224) an inconspicuous two-way radio hookup between camera truck and actors strolling through unsuspecting crowds. Tiny receiver-transmitter fits into coat pocket. Stars and extras get their orders through hearing-aid earphone. And director can eavesdrop, thanks to miniature microphone hidden under actor's tie or lapel.

A New Mass Flowmeter

From "The Momentum Principle Measures Mass Rate of Flow" by V. A. Arlando and F. B. Jennings, Aircraft Instrument Engineering Div., General Electric Co. ASME Semi-annual Meeting, Los Angeles, June 1953.

Conventional flowmeters that measure mass-flow rate have to compensate for errors due to density and viscosity changes of the fluids. These corrections are necessary because the responses of most familiar flowmeters depend on the density of the fluids being measured.

In developing a true mass flowmeter a fundamental approach is to introduce a constant velocity into the fluid. The resulting changes in energy or momentum are directly proportional to the mass-flow rate. Measurable effects can be formed, which are proportional to the mass flow rate. The measurement is usually derived from one of the following: input power of the rotating source, pressure, force, or torque generated by the fluid.

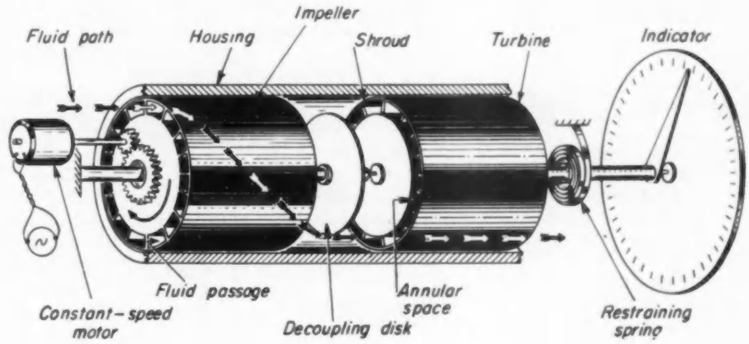
The authors developed a mass flowmeter based on the Coriolis effect which gave excellent results in actual tests. Work on it would have been carried further if the flowmeter that is the subject of this paper had not been conceived.

The reason the authors looked beyond the Coriolis flowmeter was to find, if possible, a principle which allowed a simpler, more flexible mechanical instrument design. The fundamental momentum theories, of which the Coriolis acceleration is a special case, were studied and the concepts evolved were incorporated in the instrument developed.

HOW IT WORKS

The meter consists of two similar cylinders placed end to end so that their axes align. The instrument housing closely fits the outer diameter of the cylinders. Around the periphery of the cylinders are several passages, with axes parallel to those of the cylinders. Fluid moving through the pipe enters the passages in the first cylinder, proceeds through the passages in the second cylinder, and continues along the pipe line. The upstream cylinder, termed the impeller, is motor-driven at a constant angular velocity about its axis, giving the fluid a constant velocity at right angles to the flow. This angular velocity is a change in momentum of the fluid. The second cylinder, termed the turbine, is designed to remove all the angular momentum from the fluid. In doing so, a torque is exerted on it in accordance with Newton's second law of motion. This torque deflects a spring restraining the turbine. The angular deflection of the turbine is a measure of the mass rate of flow.

Mathematically, the torque received by the turbine is proportional to the mass rate of flow, and the proportionality constant depends only on the angular velocity and dimensions of the impeller. The torque output does not depend on fluid density. In practice, the equation applies for liquids or gases, whether the flow is laminar or turbulent.



In the case of pulsating flow, the linear torque equation implies that the average turbine deflection measures the average flow rate. If the pulsation frequency is higher than the natural frequency of the turbine, the oscillations will be small and the turbine deflection will indicate the average rate of flow.

In a sample flowmeter the impeller and turbine were almost identical, being 2½ in. in diameter by 2½ in. long. A synchronous motor drove the impeller at 60 rpm. The turbine was restrained from turning by a spiral spring having a torsion constant of .0042 oz-in. per deg.

A calibration curve of the flowmeter was made using kerosene and jet-engine fuel for flows up to 9,000 lb per hr. All of the test points were accurate to within ½ per cent of the full scale range. The accuracy of the test equipment was ½ per cent of point. The maximum pressure drop across the cylinders was less than ¼ in. of water.

The highest flow rate measured to date with the sample flowmeter was 18,000 pounds per hour. There were no indications that the torque would not remain linear at higher flows.

In the theory of operation of the flowmeter, the torque necessary to supply momentum to the fluid equals the torque necessary to remove it. Therefore, to measure the mass flow rate, it is necessary to measure only the torque required to drive the impeller as the fluid passes through it. But because of the viscous torque that would be developed in the small gap between the housing and the rotating impeller, an error would result. To prevent this error, the momentum is removed from the fluid by the turbine, the resulting torque driving the turbine to a stationary position. When one considers that the rotating impeller is only a small distance from the stationary turbine, the viscous coupling between these two cylinders is immediately appreciated. A stationary disk between the cylinders reduces this effect.

CHANGING RANGE

The torque developed by the device and, therefore, the full-scale range of the instrument, can be changed by merely changing the impeller speed. At high speeds, a large error can be introduced by a torque which develops between the impeller and turbine as in an automotive fluid coupling. It stems from centrifugal force on the fluid revolving with the impeller. In tests made driving the impeller at different speeds the slopes of the linear portion of the calibration curves were directly proportional to the speed of rotation, but the angular deflection of the turbine at zero flow

rate was excessive at the higher impeller speeds.

Study of all the effects indicates that an accurate flowmeter should have long cylinders, with passages having small cross-sectional areas located at relatively large distances from the center of rotation. The impeller should rotate slowly. Both cylinders should have shrouds, the adjacent ends of which are located as close together as practical. A stationary disk should separate the cylinders. Results of repeated tests show that such a design will give consistent data, and no minor flaw in the construction will have a critical effect on the operation of the instrument.

Controlling Combustion

From "Automatic Combustion Control", by J. C. Farquhar, George Kent Ltd. "Transactions of the Society of Instrument Technology," March 1954, London.

Many engineers don't trust flue-gas analysis as a basis for complete combustion control because they feel that:

- ▶ Continuous analyzers are not sufficiently rugged and reliable.
- ▶ Sampling systems are likely to choke up or leak.
- ▶ There is an unavoidable dead-time lag in sampling, and the analyzers themselves respond slowly.
- ▶ Leakage of air, other than combustion air, into the furnace and flues upsets the reading of the analyzer.

If true, these are serious objections, but on the other hand, oxygen concentration in residual gas is the fundamental quantity that we actually have to control. The modern and reliable magnetic oxygen recorder makes possible direct closed-loop control of the quantity which has to be regulated. All other methods are only inferential, or putting it another way, they are open-loop as far as the desired quantity (residual oxygen concentration) is concerned.

Because a concentration is being measured, dead-time lag in sampling is unavoidable, and may reach serious proportions. Most systems in present operation were designed for recorders and have dead time lags of four or five minutes or even more. Free volume in the system should be reduced and rate of sampling increased. The analyzer itself should be rugged enough to mount close to the flue.

In spite of these improvements, it is often impossible to reduce dead-time lag to much under one minute.

Leakage of air (other than combustion air) into the furnace or flues before the sampling point has a far more serious effect on the efficacy of the oxygen analyzer than it has on other gas analybers, e.g., CO_2. This is because the diluent air brings in as one of its constituents the gas which is being measured by the oxygen analyzer, whereas this air only acts on the CO_2 recorder as a neutral diluent.

For instance, if after combustion, 5 per cent of air (volume per cent of flue gases) leaked in, it would increase the oxygen concentration as read by the oxygen analyzer by approximately one per cent O_2. If the oxygen was being controlled at, say 2 per cent for gas fuel, this leakage would be equivalent to a 50 per cent error in scale reading of the oxygen controller, clearly intolerable for control purposes.

Some types of furnace are inherently leaky so that oxygen control cannot ever be contemplated. An example is the open-hearth steel furnace with its frequently-opened charging doors. Leakage cannot be prevented, even by the most sensitive furnace pressure control, because of the difference in density of the gas inside and the air outside the furnace.

Much more numerous are the furnaces that should not leak but frequently do so. In this class fall water-tube boilers, refinery heaters, and similar furnaces operated at slightly less than atmospheric pressure. Proper application of oxygen control to such furnaces requires more than normal care for maintenance of refractory brickwork, operation of sight and cleaning holes, etc.

Fuel-air ratio is a logical basis for automatic combustion control wherever it can be used. In some cases, such as the open-hearth furnace, it is the only system which is practicable at present.

The main advantage of fuel-air ratio control is that lags and sensitivities of fuel-flow and air-flow controllers can be matched, so that fuel and air will vary simultaneously, no matter how fast or great the load change.

Its main limitation is the possible inaccuracy of fuel measurement, although sometimes also in the inaccuracy of air measurement.

Steam-air ratio control has been used for many years to insure good combustion conditions in steam plants. The method measures fuel input indirectly in terms of rate of steam generation and by proportioning air flow to steam flow, establishes correct combustion conditions.

Boiler efficiency varies on the average about 6 or 7 per cent throughout the full load range of the boiler. But discounting extremes of load, efficiency should be constant within 2 per cent of the mean. Commonly used boiler fuels require a uniform amount of air per Btu of heat released. This natural phenomenon and the approximation of boiler efficiency are bases for steam-air ratio combustion control.

Recording Pens That Work

From "Instrument Pens" by Leo Walter, AMIMechE, MSIT, in "Mechanical World and Engineering Record, May 1954, London.

To get full benefits from industrial recording instruments used for measurement and automatic control, they must produce clear, clean chart records. Although the plant operator can, from quite a distance, see at a glance the measured value indicated on the large scale of a modern recorder, the continuous record made by the instrument pen allows him to check at any time on the condition during each phase of the process.

The value of instrument chart records depends on accuracy of measurement, on paper quality, on reliability of the pen-moving mechanism, on ink quality (unless a stylus and coated paper are used or another inkless method, such as heat- or pressure-sensitive chart papers), and last on the design of the instrument pen itself. This article considers some of the design points in pens that transfer fluid ink continuously to the surface of a recorder chart.

The less paper dimensions vary with air temperature and humidity the sharper the accuracy of the record. Ink varies from water inks containing glycerine to special oil inks, but they all have to flow out of the pen fast enough to draw a continuous line.

FEEDBACK FACT

Posed: Controlling the muscle of an overzealous boyscout.

Solved: Robbins Instrument has a tourniquet that automatically adjusts its pressure. Self-regulating valve bleeds carbon dioxide to inflating cuff.

Inkless pens or styli require a certain pressure on waxed or otherwise coated paper to produce readable chart records. Ink pens, however, should press lightly—just enough to make ink flow, and not so much as to blur lines.

After many years of development, two main pen types seem to have emerged as standard. One system uses a trough or form of bucket reservoir containing the total ink supply, and various types are available from instrument makers. The other system separates the ink vessel from the pen and uses syphon action to make the ink flow into the pen. The advantage of a separate ink trough is that it stores a greater ink volume and keeps it clean.

The main factors to be considered for any type of pen-moving mechanism are:

▶ Sufficient force is necessary to overcome pen friction on the paper, and friction within the link mechanism.

▶ Accurate positioning of the instrument pen on the ruling lines and stability have to be assured, otherwise lines might be blurred.

▶ The mechanism should be easy to adjust.

Filled Thermometers

From "Industrial Filled-System Thermometers", an article in "Mechanical World and Engineering Record," July 1954, London.

Practical instruments for accurate temperature determination usually embody one of four principles: the expansion of fluids, the vapor pressure of liquids, the electrical resistance of conductors as affected by temperature, or the thermo-electric properties of two dissimilar wires. These cover the majority of temperature indicators or recorders in industrial use. There are, in addition, other forms of instruments, which do not measure temperature directly but measure the radiation from a hot body, from which the actual temperature is deduced.

Throughout industry the range of observations may extend from about −200 deg C (liquid oxygen, etc.) up to 2,000 deg C or even beyond. No one type of thermometer or temperature recorder can give the desired accuracy over the complete range, for each will have its particular limitations.

Filled-system thermometers em-

ploy the first two principles of operation mentioned above—thermal expansion of a liquid as a measure of the temperature of the sensing element or bulb, or a system only partially filled with liquid where the vapor pressure in the unfilled part of the system is a measure of the temperature of the bulb. A third type has a gas-filled system, indicating (or recording) temperature as a function of the thermal expansion of the gas essentially similar to the first principle except that a gas is used instead of a liquid.

All basic types of industrial filled-system thermometers are similar in that each has a bulb, capillary tubing, filling fluid, and scale measuring device. The measuring device may be no more elaborate than a scale inscribed on an envelope surrounding the capillary tubing (as in a simple mercury thermometer) or may involve linkage to some remote indicating or record-apparatus.

DESIGN FOR RUGGEDNESS

Applications of the ordinary mercury-in-glass thermometer are obviously limited and so the common industrial filled-system instrument is a rugged mercury-in-steel thermometer. It is connected by a length of capillary tubing to a Bourdon pressure gage, which controls the position of the recording pen on a rotating chart. The recorder can be remote from the bulb and thus well away from the hot zone. Even with as much as 100 ft of capillary tubing, the volume of mercury in the capillary can still be less than one per cent of the volume of mercury in the bulb.

The design of the bulb or sensing element is important for it must follow temperature changes as quickly as possible, transferring heat to the filling fluid without delay. A high ratio of surface area to bulb volume increases sensitivity. Hence most bulbs are elongated cylindrical tubes.

The capillary tubing must be manufactured to exacting tolerances. Bore may range from .006 to .028 in., although a bore of less than .010 in. retards response and is seldom used.

FEEDBACK FANCY

Needed: A simple closed-loop system for controlling auto heaters.

Suggested: Solution is obvious to the many control engineers who continue to deny their trade by fiddling with knobs on the way to work.

The measuring element in all systems is basically the same—a form of pressure gage. With a suitable linkage, this converts the pressure generated within the system by the filling fluid into a mechanical movement of a pointer or pen. Operating pressures within the filled system vary from 50 psi up to 2,000 psi.

Electronics Gages Thickness

From "Summary Technical Report 1838—Three Electronic Thickness Gages for Metallic Coatings," National Bureau of Standards, Washington, D. C.

All three gages determine the difference in electrical conductivity between a plating and the underlying metal. Even so, each senses specimen resistance differently.

Held next to the specimen, the Dermitron senses the reflected flux in a single coil energized with high frequency current. Properly calibrated, the gage works with combinations of metals, whether the plating or basis metal is magnetic or nonmagnetic.

As suggested by its name, the Phase-Angle Thickness Meter measures the phase angle between two pickup coils. Its large advantage is its insensitivity to probe-to-sample spacing.

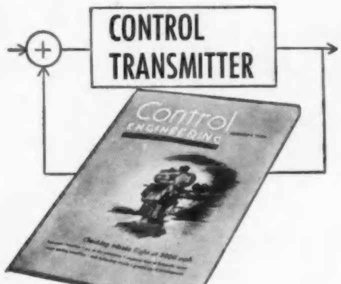
The Waveguide Plating Quantity Indicator, in contrast to the other two members of the threesome, operates on dc. The current which a feedback system requires to maintain constant potential between two probes measures conductivity.

Accelerometers Calibrated

From "Summary Technical Report 1878 — Calibration of Vibration Pickups and Accelerometers," National Bureau of Standards, Washington, D. C.

A program of basic instrumentation research sponsored by the Office of Naval Research, the Air Research and Development Command, and the Atomic Energy Commission has, among other achievements, developed several methods of calibrating vibration pickups and accelerometers. The first, developed by C. W. Kissinger of NBS, sets the acceleration level of vibration generators. The second, developed by Mr. Kissinger and T. A. Perls, also of the NBS staff, calibrates high values of sinusoidal acceleration.

The Classified Advertising Section of **CONTROL** ENGINEERING



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New Ads Received by September 30th at the New York office, 330 W. 42nd St., New York 36, N. Y., will appear in November Issue subject to limitations of space available.

control engineers

A further expansion of Honeywell's Aeronautical Division has created the following unusual opportunities. If you are interested in a permanent position with America's largest control manufacturer, consider these challenging opportunities now available at top salaries.

MECHANICAL DESIGN ENGINEER *GYROS—*

New positions open in the design of mechanical components of gyros, accelerometers, synchros and other related devices. Requires minimum of 5 years' experience in mechanical design.

HYDRAULICS DESIGN ENGINEER

New opportunity in design of hydraulic components and systems involving servos, valves, actuators for automatic flight controls. Requires engineering degree or equivalent and 5 years' design experience.

RESEARCH ENGINEER *GYROS—*

Unusual new position open in Research Department for engineer to work on extremely low friction, low error and high precision multi axis gyro platforms. Position requires a Mechanical Engineer or Physicist with experience or advanced training in machine design, gyro principles and analytical mathematics.

METHODS ENGINEER *GYROS—*

New position open as methods engineer working primarily on the assembly of precision gyros and other small devices. College degree or equivalent desirable plus 5 years' experience in similar or related work.

AERODYNAMICIST AND HELICOPTER DYNAMICIST

Two new challenging positions open for an aerodynamacist and a helicopter dynanamacist in the research phase of autopilot development. Will involve work on control dynamics of the airplane or helicopter, analytical investigations of control problems and correlation of experimental results with analytical predictions. Advanced degree in engineering, physics or mathematics or equivalent experience desired.

SERVOMECHANISM RESEARCH ENGINEER

Newly created position open in our Analytical Section studying control operations as simulated on our "Reac" computer. Work will be primarily in field of jet engine controls and will require an understanding of jet engine operation and control problems. Analog computer experience is necessary.

If you are interested in any of these well paid positions located in Honeywell's new Aeronautical Plant in Minneapolis, send your resumes to—

J. Arthur Johnson
Director of Engineering Placement
Dept. CE-10
Minneapolis-Honeywell Regulator Co.
Minneapolis 8, Minnesota

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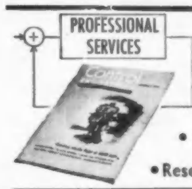
H *First in Controls*



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When you are represented in the PROFESSIONAL SERVICES SECTION of CONTROL ENGINEERING, you are contacting the executives who are responsible for calling in the experts.

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Excellent salaries, many educational opportunities, and generous employee benefits. Moving expenses paid to Endicott, N. Y.

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MAY WE HAVE YOUR ATTENTION?

The "CONTROL TRANSMITTER" serves as an active market place for buying and selling used and surplus elements and components of control systems. It will be consulted regularly by prospective buyers of such equipment offered by individual plants or dealers.

If you have used or surplus elements and components of control systems lying around idle in your plant, you can help other readers of the "CONTROL TRANSMITTER" who need such equipment by bringing it to their attention.

You may find bargains in hard-to-get components through the dealers advertising in this section. Make the reading of "CONTROL TRANSMITTER" a monthly habit.

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HERMETICALLY SEALED

SIGMA—5 RJ—2000 ohm coil		SPDT	$3.25
5 RJ— 400 ohm coil		SPDT	3.25
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STRUTHERS-DUNN—	28v DC—	DPDT	3.75
ALLIED	— 28v DC—	4PDT	4.85
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ADVANCE	—115v AC—	SPST-NO	5.50

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Specializing in all types of Relays

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PYROMETER mod 16 size 4⅝" panel mount 11 milivolt F.S. Dual scale 0-1100 deg C & 0-2000 deg F. Suitable for chrmel and alumel thermocouple. With compensating adj screws. $16.50.

RIGHT ANGLE THERMOMETER mercury type minus 35 degrees C. to plus 15 degrees C. Mfd. Taylor inst. size 14" x 12". $3.50.

HERSHEL RADIO COMPANY
5245 Grand River Detroit 8, Michigan

ATTENTION! CONTROL ENGINEERS

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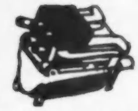
We have a large variety of standard types of relays and solenoids for every application. When inquiring about your needs, give as much information as possible.



MINIATURE RELAYS

AUTOMATIC ELECTRIC CLASS S: Twin Code O 20 ga Contacts; Available in the following 24VDC, 300 ohm types:
—3A; #R340 .... 1.25
—2A, 2C; #R341 .... 1.50
—4A; #R342 .... 1.50
—5A; 1B; #R343 .... 1.75
—24VDC; 640 ohm; 1C, 1B; #R640 .... 1.25
—3ma; 8000 ohm; 1A; #R641 .... 2.60

COOK 482; 24VDC; DPDT; 500 ohm #R918 .. 1.50
G.E. CR2791G110F2 24VDC; DPDT; 300 ohm; #R919 .... 1.25
CLARE A20545; 8VDC; 1B; 45 ohm; #R920 .. 1.00
AUTOMATIC 754A; 12VDC; DPDT 6 Amp; 200 ohm; #R921 .... 1.50
AUTOMATIC 754; 6VDC; DPDT 6 Amp; 50 ohm; #R922 .... 1.50
ALLIED SK; 6VDC; 1 H; 14.5 ohm; #R335 .. 1.25
ALLIED CB5; 24VDC; SPDT; 300 ohm #R330 1.00
ALLIED SK: 8.5 ma; 4500 ohm; DPDT; #R1015 .... 2.25
ALLIED FID: 8 ma; 1A; 3000 ohm; #R916 .. 1.25
RBM 23024; 6 ma; 4PST n.o. (4A's); 6500 ohm; #R802 .... 2.50
LEACH P3; 3 ma; SPDT; 1280 ohm; #R941 ... 1.25
SIGMA 41F; 12VDC; SPDT; 340 ohm; #R925 .. 1.95
SIGMA 4F8000S; 1 ma; SPDT; 8000 ohm; #R287 .... 5.95
SIGMA 41FS7; 2 ma; SPDT; 10000 ohm; #R914 .... 1.95
SIGMA 41F80000S: 2.5 ma; SPDT; 8000 ohm; #R1002 .... 2.25
D163221 AMER. TOTALIZER, 24 VDC, DPDT 300 ohms, Anti-Capacity Arms, #R134 .... 1.50
CLARE K: 24VDC; DPDT; 300 ohm #R331 .. 1.25
CLARE K: 24VDC; 3PDT; 300 ohm; #R332 .. 1.75
CLARE K; 24VDC; 4PDT; 300 ohm; #R524 .. 2.50
CLARE K: 25ma; 2A, 2C†; 2000 ohms; #R333 2.00
ADVANCE K1504: 24VAC; 2A†; 450 ohm; #R334 .... 1.00
COOK R10: 24VDC; 3A (1 contact 10 amp); 250 ohm; #R427 .... 1.50
ADVANCE K1604; 12½ ma; DPDT; 6500 ohm; #R532 .... 2.00
ADVANCE K1504; 220VAC; DPDT; #R531 .. 2.00
ADVANCE K1604: 3VDC; 14.5 ohm; DPDT; #R795 .... 2.00
PRICE 1050: 7 ma; 2800 ohm; DPDT; #R1016 .... 2.25
PRICE 1050: 5 ma; 6500 ohm; DPDT; #R1017 2.50
MINIATURE SK: 24VDC; DPDT; 425 ohm #R795 .... 1.50
MINIATURE SK: 24VDC; 3 PDT; 425 ohm; #R796 .... 2.50
MINIATURE SK 24VDC; 4DPT; 425 ohms; #R525 .... 2.75
23012-0 RBM, 24VDC, SPDT, 250 ohms. #R172 .... 1.25
7251 ARC, 24 VDC, SPDT, 300 ohm #R406 .. 1.25
7252 ARC, 24 VDC, DPST, n.o. (2A's) 300 ohm, Anti-Capacity Arms, Ceramic Insulation, #R354 .... 1.25
P3 LEACH (Pair on Bakelite Strip) Each relay; VDC, SPDT, 1 ohm #R353 .... pr 2.50
73A23 ALLIED, 24VDC, Make 3 Break 1, (2As. 1C) 300 ohms, #R403 .... ea. 1.50
TB 302 PRICE, 24VDC, Make 3, Break 1, (2 As. 1C) 300 ohms, #R404 .... ea. 1.50

†-SPST, n.o.; B-SPST, n.c.; C-SPDT; H-Double Break

AND MANY OTHERS

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